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Detailed assessment of the reported economic costs of invasive species in Australia

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Abstract

The legacy of deliberate and accidental introductions of invasive alien species to Australia has had a hefty economic toll, yet quantifying the magnitude of the costs associated with direct loss and damage, as well as for management interventions, remains elusive. This is because the reliability of cost estimates and undersampling have not been determined. We provide the first detailed analysis of the reported costs associated

with invasive species to the Australian economy since the 1960s, based on the recently published InvaCost database and supplementary information, for a total of 2078 unique cost entries. Since the 1960s, Australia has spent or incurred losses totalling at least US$298.58 billion (2017 value) or AU$389.59 billion (2017 average exchange rate) from invasive species. However, this is an underestimate given that costs rise as the number of estimates increases following a power law. There was an average 1.8–6.3-fold increase in the total costs per decade since the 1970s to the present, producing estimated costs of US$6.09–57.91 billion year^{-1} (all costs combined) or US$225.31 million–6.84 billion year^{-1} (observed, highly reliable costs only). Costs arising from plant species were the highest among kingdoms (US$151.68 billion), although most of the costs were not attributable to single species. Of the identified weedy species, the costliest were annual ryegrass (*Lolium rigidum*), parthenium (*Parthenium hysterophorus*) and ragwort (*Senecio jacobaea*). The four costliest classes were mammals (US$48.63 billion), insects (US$11.95 billion), eudicots (US$4.10 billion) and monocots (US$1.92 billion). The three costliest species were all animals – cats (*Felis catus*), rabbits (*Oryctolagus cuniculus*) and red imported fire ants (*Solenopsis invicta*). Each State/Territory had a different suite of major costs by species, but with most (3–62%) costs derived from one to three species per political unit. Most (61%) of the reported costs applied to multiple environments and 73% of the total pertained to direct damage or loss compared to management costs only, with both of these findings reflecting the availability of data. Rising incursions of invasive species will continue to have substantial costs for the Australian economy, but with better investment, standardised assessments and reporting and coordinated interventions (including eradications), some of these costs could be substantially reduced.

Abstract in Pitjantjatjara

Kuka munu ukiṟi kutjupa tjuṯangku manta nganampa kurantja alatjiṯu. Kuḻi kutjupa kuḻi kutjupa aṉangu kutjupa tjuṯangku kuka kutjupa kutjupa tjuṯa munu punu kutjupa kutjupa tjuṯa ngura kutjupa pararinguṟu ngalya-katipai Australiala-kutu. Ka kuka munu punu nyanga malikitja tjuṯangku ngura nganampa kuralpai alatjitu, kala palulanguṟu nganaṉa mani puḻkangka payamilalpai ngura wiṟuṟa kanyintjikitjangku, mani nampa nyangangka 6,000,000,000 dollars, mani puḻka mulata. Palu nganaṉa mani puḻka mulata manti payamilalpai mani panya palula munkara alatjitu, panya nganaṉa tjukutjukuku kutju ninti kukaku munu punuku paluṟu tjana panya manta nyanga kurannyangka. Panya kuka munu punu tjuṯangku manti ngura nyanga palunya puḻkaṟa kuraṉi, kala tjukutjukuku kutju nintiringu. Ka kutjupa tjuṯangku ngura kutjupanguṟu uṉinypa kura ngalya-katira manta nyanga palula para-waṉira waṉannyangka ukiṟi kura mulapa pakaṟa puḻkaringkupai munu lipiringkupai manta winkingka uṉinypa panya palulanguṟu, munu manta kuralpai alatjiṯu. Ka pala palu puṟunytju kuka kutjupa tjuṯangku puḻkaṟa kuralpai manta nyanga nganampa, kuka nyangantu: ngaya, putji, rapita munu minga kura, minga panya muṯuta, pikati puḻka. Kuka nyanga paluṟu tjana manta kuralpai alatjiṯu ukiṟingka munkara alatjiṯu. Tjinguṟu aṉangu tjuṯangku titutjarangku kutjupa kutjupa tjuṯa ngura kutjupa-nguṟu ngalya-katinyangkampa ka paluṟu tjana puḻkaṟa kuralku manta nyanga palunya. Palu nganaṉa uti manta panya wiṟuṟa kanyinma, kutjupa tjuṯangku kurantjaku-tawara. Munu palulanguṟu nganaṉa mani puḻkangka payamilantja wiya ngura nyangatja palya ngaṟanyangka.

Abstract in Chinese

对澳大利亚已报道的入侵物种造成经济损失的详细评估

无意和有意引入的外来入侵物种已经给澳大利亚的经济造成了巨大损失。然而，对生物入侵造成的经济损失和相应的管理投入进行定量仍较困难，因为我们当前缺乏可靠且全面的生物入侵造成经济损失的数据。为填补这一空缺，我们利用最近发表的InvaCost数据库及其相应的补充信息，根据自20世纪60年代以来报道的2078条数据，首次分析了生物入侵对澳大利亚经济造成的损失。自20世纪60年代以来，生物入侵已经澳大利亚造成了至少2985.8亿美元（2017年的价值）或3895.9亿澳元的经济损失（2017年的平均汇率)。然而，这一数字仍被

低估，因为经济损失会随着数据数量的增加而呈幂律上升。20世纪70年代至今，经济损失平均每十年便会增加1.8–6.3倍，其对应的增长速度为60.9–57.1亿美元/年（所有损失的数据)，或2.2531亿-68.4亿美 元/年（仅考虑实测到的且可靠较高的数据)。外来植物入侵产生的损失为各生物界中最高的(1516.8亿美元)，尽管大部分的损失不是由单一物种造成。在已确定的入侵杂草中，造成经济损失最高的物种是硬直黑麦草 (*Lolium rigidum*)、银胶菊 (*Parthenium hysterophorus*) 和新疆千里光 (*Senecio jacobaea*)。造成经济损失最高的四个类群分别是哺乳动物 (486.3亿美元)、昆虫 (119.5亿美元)、真双子叶植物 (41.0亿美元)和单子叶植物 (19.2亿美元)。造成经济损失最高的 三个物种都是动物，分别为家猫 (*Felis catus*)、家兔 (*Oryctolagus cuniculus*) 和入侵红火蚁 (*Solenopsis invicta*)。每个州/领地的主要经济损失由不同 物种造成，但是各行政单元的大多数 (3–62%) 损失可归于一至三个物种。大多数 (61%) 经济损失是由入侵物种在多个环境中造成 的，且73%的总损失与直接的经济损失相关，而非与管理投入相关。这两个结果反映了数据的可用性。日益增多的入侵物种将持续对澳大利亚的经济造成巨大损失。但是，如果有更合理的经费投入、标准化的评估和报告、以及协调的干预措施 (包括根除)，生物入侵造成的经济损失 可被极大地降低。

Abstract in Bahasa Indonesia

Kajian lengkap mengenai kerugian ekonomi yang diakibatkan oleh spesies invasif di Australia. Dampak dari masuknya spesies invasif, baik secara sengaja maupun tidak, ke dalam Australia telah mengakibatkan kerugian perekonomian yang besar, namun mengukur besarnya kerugian yang terkait biaya dan kerusakan secara langsung, juga terkait pengeluaran untuk manajemen intervensi, masih sulit untuk dilakukan. Hal ini karena tingkat keandalan dari estimasi kerugian dan pengambilan sampel belum diketahui. Di sini kami memaparkan analisis mendetil untuk pertama kalinya mengenai kerugian yang terkait dengan keberadaan spesies invasif terhadap perekonomian Australia sejak tahun 1960an, berdasarkan *database* InvaCost yang baru-baru ini dipublikasikan dan informasi tambahan lainnya, dengan total 2078 buah entri unik terkait biaya kerugian. Sejak tahun 1960an, Australia telah mengeluarkan atau mengalami kerugian yang mencapai setidaknya US$295.58 milyar (nilai tahun 2017) atau AU$389.59 milyar (nilai tukar 2017) akibat keberadaan spesies invasif. Namun, nilai ini masih merupakan estimasi yang lebih rendah dari yang sesungguhnya dikarenakan oleh peningkatan kerugian secara eksponensial seiring bertambahnya data. Secara rata-rata terdapat peningkatan secara 1.8–6.3 kali dari biaya kerugian total untuk setiap dekade sejak 1970an hingga sekarang, menghasilkan estimasi kerugian sebesar US$6.09–57.91 milyar per tahun (seluruh biaya disatukan) atau US$225.31 juta–6.84 milyar per tahun (teramati, hanya nilai kerugian yang dapat diandalkan). Kerugian yang dihasilkan dari spesies tumbuhan paling tinggi diantara kingdom yang lain (US$151.68 milyar), namun sebagian besar dari kerugian ini tidak diakibatkan oleh spesies tunggal. Dari tanaman rumput liar yang teridentifikasi, yang paling besar mengakibatkan kerugian adalah rumput *Lolium rigidum*, rumput *Parthenium hysterophorus*, dan rumput *Senecio jacobaea*. Untuk tingkatan kelas, yang mengakibatkan kerugian paling besar adalah mamalia (US$48.63 milyar), serangga (US$11.95 milyar), tanaman dikotil sejati/eudikot (US$4.10 milyar) dan monokotil (US$1.92 milyar). Untuk tingkatan spesies, tiga spesies yang paling mengakibatkan kerugian adalah spesies hewan, yaitu kucing (*Felis catus*), kelinci (*Oryctolagus cuniculus*) dan semut api (*Solenopsis invicta*). Setiap negara bagian memiliki pola kerugian terbesar yang berbeda berdasarkan jenis spesies, namun kerugian terbesar (3–62%) datang dari satu hingga tiga spesies per unit politik. Sebagian besar (61%) dari kerugian yang terlaporkan terjadi pada berberapa jenis lingkungan dan 73% dari keseluruhan termasuk ke dalam kerusakan atau kerugian secara langsung dibandingkan dengan biaya manajemen saja, dengan catatan bahwa kedua penemuan ini mencerminkan ketersediaan data. Peningkatan masuknya spesies invasif akan terus menghasilkan kerugian yang nyata untuk perekonomian Australia, namun dengan investasi yang lebih baik, penyeragaman dari pengukuran dan pelaporan dan juga pengkoordinasian intervensi (termasuk pembasmian), beberapa kerugian ini dapat dikurangi secara substansial.

Abstract in Tok Pisin

Stadi lon painim aut kostim lon ol nogut binatang na diwai kam insait lon Austrelia. Taim ol nogut binatang na diwai bilong longwe ples kamap lo Austrelia, ol bagarapim kantri stret. Tasol em hatwok yet lon lukim hamas stret moni dispela bagarap em givim lo kantri. Dispela em bikos nogat gutpela stadi lo kostim em kamap yet. Tasol nau, dispela em nambawan stadi em lukluk lon hamas stret moni Austrelia usim lon lukautim na managim dispela wari (lon ol nogut binatang na diwai kam insait lo kantri), lon 1960s kam inap nau; ol wokman lo stadi lukluk lon kainkain save lon mekim dispela kostim. Bifo lon 1960s kam inap nau, Austrelia givim moni mak olsem US$298.58 billion (lon 2017) or AU$389.59 billion (lon 2017 namel namba) lo lukautim ol yet lon binatang nogut. Tasol dispela moni mak em ino stret tumas bilong wanem ol namba save senis olgeta taim. Na tu, lon 1970s kam, ibin gat 1.8–6.3% moa kostim olgeta tenpela yia kam inap tede, moni mak olsem US$6.09–57.91 billion yia-1 (olgeta kostim wantaim) or US$225.31 million–6.84 billion. Ol kostim bilong olgeta nogut diwai wantaim em bikpela olgeta (US$151.68 billion). Lo sait blo gras nogut, sampela olsem *ryegrass* (*Lolium rigidum*), *parthenium* (*Parthenium hysterophorus*) na *ragwort* (*Senecio jacobaea*) em planti moni stret. Na tu, lon sait lon banisim ol abus, ol *mammal* (US$48.63 billion), binatang (US$11.95 billion), *eudicots* (US$4.10 billion) na *monocot* (US$1.92 billion) usim planti moni tu. Lon sait lon banisim olgeta abus wantaim, ol pusi (*Felis catus*), *rabbit* (*Oryctolagus cuniculus*) na retpela paia anis (*Solenopsis invicta*) usim bikpela moni stret. Olgeta provins lo Austrelia givim planti moni lo lukautim ol yet lon ol nogut binatang na diwai, tasol dispela moni ol givim (3–62%) save go lon wanpla or tripela binatang/diwai nogut tasol. Planti lon dispela moni (61%) em ol provins givim lon lukautim planti kainkain bus/bikbus insait lo graun blo ol, na 73% lo dispela olgeta moni em ol usim lon lukautim bus/bikbus we binatang bagarapim pinis; ol no usim moni lo sait lo lukautim bifo bus/bikbus bagarup. Tede, ol nogut binatang na diwai kam insait lo Austrelia na wok lon bagarapim kantri yet, tasol sapos igat moa moni, and tu ol ripot na wok bung wantaim kamap, sampela dispela ol kostim bai go daun.

Abstract in French

Estimation de l'ensemble des coûts économiques des espèces exotiques envahissantes en Australie. L'histoire des introductions intentionnelles et accidentelles des espèces exotiques envahissantes en Australie a un coût économique élevé. La quantification de l'ampleur de ce coût associé aux pertes directes ainsi qu'aux dommages demeure pourtant inconnue. La difficulté d'arriver à une estimation robuste du montant total est exacerbée par un échantillonnage insuffisant et un manque de protocoles pour déterminer la robustesse des estimations de coûts individuels. Nous fournissons le premier bilan des coûts associés aux espèces envahissantes à l'économie australienne depuis les années 1960, à partir de la base de données InvaCost récemment publiée, enrichie d'estimations supplémentaires. À partir de 2078 estimations uniques de coûts, nous estimons que l'Australie a subi un coût total de US$298,58 milliards (valeur 2017, soit AU$389,59 milliards). Ce total doit cependant être une sous-estimation parce que les coûts augmentent exponentiellement avec le nombre d'estimations. Le taux d'augmentation des coûts par décennie était de 1,8 à 6,3 fois depuis les années 1970 jusqu'au présent, ce qui indique un montant annuel de US$6,09–57,91 milliards (tous les coûts compris), soit US$2,25 millions à 6,84 milliards par an (coûts observés et robustes uniquement). Les coûts associés aux espèces végétales (US$151,68 milliards) étaient les plus élevés parmi les règnes que nous avons considérés, même si la plupart de ce montant était associée aux groupements d'espèces et non aux espèces individuelles. Parmi les plantes, les coûts les plus élevés sont venus de l'ivraie raide (*Lolium rigidum*), l'absinthe marron (*Parthenium hysterophorus*) et le séneçon jacobé (*Senecio jacobaea*). Les classes les plus coûteuses étaient respectivement les mammifères (US$48,63 milliards), les insectes (US$11,95 milliards), les Eudicotylédones (US$4,10 milliards) et les Monocotylédones (US$1,92 milliards). Les espèces individuelles les plus coûteuses étaient tous les animaux : le chat haret (*Felis catus*), le lapin européen (*Oryctolagus cuniculus*) et la fourmi de feu (*Solenopsis invicta*). Le bilan de

coûts dominants différait selon l'unité politique (états et territoires), mais la plupart (entre 3 et 62% selon l'unité politique) provenait d'une à trois espèces. La majorité (61%) des coûts se rapportait aux plusieurs environnements et 73% du montant total était associés aux dommages ou aux pertes directes (ex, coûts de gestion), qui reflètent la disponibilité des données. L'augmentation des espèces exotiques envahissantes va occasionner des coûts considérables à l'économie australienne dans les années à venir. De meilleurs investissements, des évaluations standardisées, et des interventions bien organisées pourraient cependant contribuer à une réduction considérable des coûts venant des espèces exotiques envahissantes dans le pays.

Abstract in Spanish

Evaluación detallada de los costos económicos registrados de las especies invasoras en Australia. El legado de introducciones deliberadas y accidentales de especies exóticas invasoras en Australia ha tenido un costo económico considerable, sin embargo la cuantificación de la magnitud de los costos asociados con las pérdidas y daños directos, así como de las intervenciones de manejo, sigue siendo difícil de realizar. Esto se debe a que no se ha determinado la confiabilidad de las estimaciones de costos y el submuestreo. En este trabajo, proporcionamos el primer análisis detallado de los costos reportados asociados a especies invasoras para la economía australiana desde la década de 1960, basado en la base de datos InvaCost recientemente publicada e información complementaria para un total de 2078 registros únicos de costos. Desde la década de 1960, Australia ha gastado o incurrido en pérdidas un total de al menos US $298,58 mil millones (valor de 2017) o AU $389,59 mil millones (tipo de cambio promedio de 2017) debido a especies invasoras. Sin embargo, esto es una subestimación dado que los costos aumentan a medida que aumenta el número de estimaciones siguiendo una ley de potencia. Hubo un aumento promedio de 1.8 a 6.3 veces en los costos totales por década desde la década de 1970 hasta el presente, produciendo costos estimados de US $6,09 a 57,91 mil millones año^{-1} (todos los costos combinados) o US $225,31 millones a US $6,84 mil millones año^{-1} (solo costos observados, altamente confiables). Los costos derivados de especies de plantas fueron los más altos entre todos los reinos (US $151,68 mil millones), aunque la mayoría de los costos no se atribuyeron a una sola especie. De las especies de malezas identificadas, las más costosas fueron el raigrás anual (*Lolium rigidum*), la falsa altamisa (*Parthenium hysterophorus*) y la hierba cana (*Senecio jacobaea*). Las cuatro clases más costosas fueron mamíferos (US $48,63 mil millones), insectos (US $11,95 mil millones), eudicotiledoneas (US $4,10 mil millones) y monocotiledóneas (US $1,92 mil millones). Las tres especies que produjeron los mayores costos fueron animales: gatos (*Felis catus*), conejos (*Oryctolagus cuniculus*) y hormigas rojas importadas (*Solenopsis invicta*). Cada estado / territorio tuvo un conjunto diferente de costos principales por especie, pero la mayoría de los costos (3–62%) derivaron de una a tres especies por unidad política. La mayoría (61%) de los costos reportados aplicaron a múltiples hábitats y el 73% del total de costos correspondió a daños o pérdidas directas en comparación con los costos de manejo únicamente, ambos hallazgos reflejan la disponibilidad de datos. El aumento de las incursiones de especies invasoras seguirá teniendo costos sustanciales para la economía australiana, pero con una mejor inversión, estandarización de evaluaciones y de informes e intervenciones coordinadas (incluidas las erradicaciones), algunos de estos costos podrían reducirse considerablemente.

Abstract in Portuguese

Avaliacão detalhada dos registos de custos económicos associados a espécies invasoras na Austrália. O legado de introduções deliberadas e acidentais de espécies exóticas invasoras na Austrália tem resultado em custos económicos consideráveis. Contudo, calcular a magnitude dos custos associados a perdas diretas e danos, bem como dos custos associados com intervenções de gestão, não é imediato. Este desfazamento está relacionado com o nível indeterminado de confiança nas estimativas de custo e com a sub-amostragem. Nós providenciamos a primeira análise detalhada dos registos australianos de custos associados a espécies invasoras desde os anos 60, com base na publicação recente da database InvaCost e

respectiva informação complementar, para o total de 2078 registos únicos de custo. Desde a década de 1960, a Austrália incorreu um gasto total de, no mínimo, US$298.58 mil milhões (valor de 2017) ou AU$389.59 mil milhões (ao câmbio medio de 2017) devido a espécies invasoras. Este valor está contudo subestimado, uma vez que o custo aumenta com o aumento de estimativas de custo de acordo com o modelo da lei de potência. Houve, em média, um aumento de 1.8 a 6.3 vezes no custo total por década desde os anos 70 até ao presente, levando a uma estimativa de custo de US$6.09 a 57.91 mil milhões ano^{-1} (para todos os custos combinados) ou US$225.31 milhões a 6.84 mil milhões ano^{-1} (só para custos observados, de elevada confiança). Os custos derivados de espécies de plantas foram os mais altos de entre todos os reinos taxonómicos (US$151.68 mil milhões), embora a maioria dos custos não possam ser atribuídos a uma única espécie. Das espécies de ervas daninhas identificadas, as que resultaram em custos mais elevados foram o azevém anual (*Lolium rigidum*), a artemísia falsa (*Parthenium hysterophorus*) e a tasninha (*Senecio jacobaea*). As quatro classes taxonómicas mais caras foram: mamíferos (US$48.63 mil milhões), insectos (US$11.95 mil milhões), eudicotiledóneas (US$4.10 mil milhões) e monocotiledóneas (US$1.92 mil milhões). As três espécies mais caras corresponderam aos seguintes animais – gatos (*Felis catus*), coelhos (*Oryctolagus cuniculus*) e formigas de fogo (*Solenopsis invicta*). Cada Estado ou Território australiano teve um conjunto diferente de custos principais por espécie, mas a maioria (3–62%) dos custos foram associados com uma, ou até três, espécies por unidade política. A maioria (61%) dos custos registados foram aplicados a múltiplos ambientes e 73% do total de custos correspondeu a danos ou perdas diretas em comparação com apenas os custos de gestão; ambos os resultados refletindo a disponibilidade de dados. O aumento de espécies invasoras vai continuar a ter um custo substancial na economia Australiana, mas com um melhor plano de investimento, com padrões iguais para avaliações e registos e com intervenções coordenadas (incluindo extermínio), alguns destes custos podem ser substancialmente reduzidos.

Abstract in Italian

Stima dei costi economici riportati delle specie esotiche invasive in Australia. Il lascito delle introduzioni intenzionali o accidentali di specie aliene invasive in Australia ha avuto un pesante conto, ciononostante, la quantificazione della magnitudine dei costi associati alla perdita diretta e ai danni, così come agli interventi di gestione, rimane elusiva. Questo perché l'attendibilità delle stime dei costi e i sottocampionamenti non sono stati determinati. Noi forniamo la prima analisi dettagliata dei costi riportati per l'economia australiana associati alle specie invasive dagli anni '60, basati sulla banca dati recentemente pubblicata InvaCost e informazioni supplementari, per un totale di 2078 voci di costo univoche. Dagli anni '60, l'Australia ha speso o ha subito perdite per un totale di almeno 298,58 miliardi di $ americani (valore del 2017) o 389,59 miliardi di $ australiani (tasso medio di conversione del 2017) per le specie invasive. Comunque, questa è una sottostima, dato che i costi aumentano all'aumentare del numero di stime, seguendo una legge di potenza. C'è un aumento medio nei costi totali di 1,8–6,3 volte per decennio dagli anni '70 ad oggi, producendo costi stimati a 6,09–57,91 miliardi di $ americani all'anno (tutti i costi combinati) o 225,31 milioni-6,84 miliardi di $ americani all'anno (solo costi osservati e con alta attendibilità). I costi derivanti dalle specie vegetali sono quelli più alti tra i regni (151,68 miliardi di $ americani), sebbene la maggior parte dei costi non sia attribuibile a singole specie. Tra le specie infestanti identificate, le più costose sono il loglio rigido (*Lolium rigidum*), il partenio (*Parthenium hysterophorus*) e il senecione di S. Giacomo (*Senecio jacobaea*). Le quattro classi più costose sono: mammiferi (48,63 miliardi di $ americani), insetti (11,95 miliardi di $ americani), eudicotiledoni (4,10 miliardi di $ americani) e monocotiledoni (1,92 miliardi di $ americani). Le tre specie più costose sono animali: il gatto domestico (*Felis catus*), il coniglio selvatico europeo (*Oryctolagus cuniculus*) e la formica fuoco (*Solenopsis invicta*). Ogni Stato/territorio ha una diversa serie di costi principali per specie, ma la maggior parte dei costi (3–62%) deriva da una a tre specie per unità politica. La maggior parte dei costi riportati (61%) si applica a più ambienti e il 73% del totale riguarda il danno diretto o la perdita, piuttosto che i costi di sola gestione,

con entrambi questi risultati che riflettono la disponibilità di dati. Le crescenti incursioni delle specie invasive continueranno ad avere costi notevoli per l'economia australiana, ma con un migliore investimento, monitoraggi e rendicontazioni standardizzati e interventi coordinati (comprese le eradicazioni), alcuni di questi costi potrebbero essere sostanzialmente ridotti.

Abstract in German

Detaillierte Bewertung der gemeldeten wirtschaftlichen Kosten invasiver Arten in Australien. Die absichtlichen und versehentlichen Einschleppungen invasiver gebietsfremder Arten in Australien haben einen hohen wirtschaftlichen Tribut gefordert, doch die Quantifizierung der Höhe der Kosten, die mit direkten Verlusten und Schäden sowie für Management-Interventionen verbunden sind, ist nach wie vor schwer fassbar. Dies liegt daran, dass die Zuverlässigkeit von Kostenschätzungen nicht ermittelt wurde. Diese erste detaillierte Analyse der gemeldeten Kosten für invasive Arten für die australische Wirtschaft basiert auf der Grundlage der kürzlich veröffentlichten InvaCost-Datenbank und zusätzlich bezogener Informationen und somit insgesamt 2078 eindeutigen Kosten-Einträgen. Seit den 1960er Jahren hat Australien Verluste in Höhe von mindestens 298,58 Mrd. USD (Wert 2017) oder 389,59 Mrd. AU $ (durchschnittlicher Wechselkurs 2017) für invasive Arten verzeichnet. Dies ist jedoch eine Unterschätzung, da die Kosten steigen, wenn die Anzahl der Schätzungen nach dem Potenzgesetz zunimmt. Seit den 1970er Jahren haben sich die Gesamtkosten pro Jahrzehnt um das 1,8- bis 6,3-fache erhöht, was geschätzte Kosten von 6,09 bis 57,91 Milliarden US-Dollar (alle Kosten) oder 225,31 Millionen US-Dollar bis 6,84 Milliarden US-Dollar (empirisch beobachtete, zuverlässige Kosten) pro Jahr zur Folge hatte. Die Kosten für Pflanzenarten waren am höchsten (151,68 Mrd. USD), obwohl die meisten Kosten nicht auf einzelne Arten entfielen. Von den identifizierten Unkraut-Artigen Pflanzen waren die teuersten das einjährige Weidelgras (*Lolium Rigidum*), Parthenium (*Parthenium hysterophorus*) und das Kreuzkraut *(Senecio jacobaea)*. Die vier teuersten Klassen waren Säugetiere (48,63 Milliarden US-Dollar), Insekten (11,95 Milliarden US-Dollar), Eudicots (4,10 Milliarden US-Dollar) und Monocots (1,92 Milliarden US-Dollar). Die drei teuersten Arten waren alle Tiere – Katzen (*Felis catus*), Kaninchen (*Oryctolagus cuniculus*) und die rote Feuerameise (*Solenopsis invicta*). Jeder Staat bzw. jedes Territorium hatte eine andere Reihe von Hauptkosten nach Arten, wobei die meisten (3–62%) Kosten von je ein bis drei Arten stammen. Die meisten (61%) der gemeldeten Kosten entfielen auf mehrere Umgebungen und 73% der Gesamtkosten betrafen direkte Schäden oder Verluste im Vergleich zu nur den Verwaltungskosten, wobei beide Ergebnisse die Verfügbarkeit von Daten widerspiegeln. Ansteigende Raten biologischer Invasionen werden weiterhin erhebliche Kosten für die australische Wirtschaft verursachen, aber durch bessere Investitionen, standardisierte Bewertungen und Berichterstattung sowie koordinierte Interventionen (einschließlich Ausrottungen) könnten einige dieser Kosten erheblich gesenkt werden.

Abstract in Swedish

Detaljerad bedömning av de rapporterade ekonomiska kostnaderna för invasiva arter i Australien. Arvet efter avsiktlig och oavsiktlig introduktion av invasiva främmande arter till Australien har medfört en kraftig ekonomisk skada, men att kvantifiera storleken på kostnaderna förknippade med direkt förlust och skada, liksom för ledningsinsatser, är fortfarande svårgripbart. Detta beror på att tillförlitligheten hos kostnadsberäkningar och underprovtagning inte har fastställts. Vi tillhandahåller den första detaljerade analysen av de rapporterade kostnaderna för invasiva arter till den australiensiska ekonomin sedan 1960-talet, baserat på den nyligen publicerade InvaCost-databasen och kompletterande information, för totalt 2078 unika kostnadsuppgifter. Sedan 1960-talet har Australien spenderat eller drabbats av förluster på minst 298,58 miljarder USD (2017 års värde) eller 389,59 miljarder AUD (genomsnittlig växelkurs 2017) från invasiva arter. Detta är dock en underskattning med tanke på att kostnaderna stiger när antalet uppskattningar ökar enligt en potenslag. De totala kostnaderna per årtionde sedan 1970-talet fram till idag

ökade i genomsnitt 1,8–6,3 gånger vilket gav uppskattade kostnader på 6,09–57,91 miljarder USD/år (alla kostnader sammanlagt) eller 225,31 miljoner – 6,84 miljarder USD/år (observerade, endast mycket tillförlitliga kostnader). Kostnaderna för växtarter var de högsta bland rikena (151,68 miljarder USD), även om de flesta kostnaderna inte kan hänföras till enskilda arter. Av de identifierade ogräsarterna var de dyraste årlig Styvrepe (*Lolium rigidum*), Flikpartenium (*Parthenium hysterophorus*) och Stånds (*Senecio jacobaea*). De fyra dyraste klasserna var däggdjur (48,63 miljarder USD), insekter (11,95 miljarder USD), eudicots (4,10 miljarder USD) och monocots (1,92 miljarder USD). De tre dyraste arterna var alla djur – katter (*Felis catus*), kaniner (*Oryctolagus cuniculus*) och röda importerade eldmyror (*Solenopsis invicta*). Varje stat/territorium hade en skild uppsättning av kostnader per art, men de flesta (3–62%) av kostnaderna härrör från en till tre arter per politisk enhet. De flesta (61%) av de rapporterade kostnaderna tillämpades på flera miljöer och 73% av totalen avsåg direkt skada eller förlust jämfört med endast förvaltningskostnader, varvid båda dessa resultat återspeglar tillgängligheten av data. Stigande invasioner av invasiva arter kommer att fortsätta medföra betydande kostnader för den australiensiska ekonomin men med bättre investeringar, standardiserade bedömningar och rapportering och samordnade insatser (inklusive utrotningar) kan en del av dessa kostnader minskas avsevärt.

Abstract in Greek

Λεπτομερής εκτίμηση του καταγεγραμμένου οικονομικού κόστους των χωροκατακτητικών ειδών στην Αυστραλία. Οι συνέπειες των τυχαίων και μη εισαγωγών χωροκατακτητικών ειδών στην Αυστραλία έχουν βαρύ οικονομικό τίμημα, αν και η ποσοτικοποίηση του κόστους, το οποίο σχετίζεται με την άμεση εξαφάνιση ή βλάβη, όπως και με τις διαχειριστικές παρεμβάσεις, παραμένει ελλιπής. Αυτό συμβαίνει διότι η αξιοπιστία των εκτιμήσεων κόστους και η μη-αντιπροσωπευτική δειγματοληψία δεν έχουν διερευνηθεί. Εδώ παρέχουμε την πρώτη λεπτομερή ανάλυση του αναφερθέντος οικονομικού αντίκτυπου που είχαν τα χωροκατακτητικά είδη στην οικονομία της Αυστραλίας από τη δεκαετία του 1960, βασιζόμενοι στην βάση δεδομένων InvaCost, η οποία δημοσιεύθηκε πρόσφατα, και άλλες συμπληρωματικές πληροφορίες, για ένα σύνολο 2078 μοναδικών καταχωρίσεων κόστους. Από τη δεκαετία του 1960, η Αυστραλία έχει δαπανήσει ή υπόκειται σε απώλειες συνολικού ύψους τουλάχιστον 298,58 δις δολαρίων (σε αξία 2017) ή 389,59 δις δολαρίων Αυστραλίας (μέσος δείκτης συναλλαγματικής ισοτιμίας του 2017) εξαιτίας των χωροκατακτητικών ειδών. Ωστόσο, πρόκειται σαφώς για υποτίμηση, δεδομένου ότι το κόστος αυξάνεται όσο αυξάνεται ο αριθμός των εκτιμήσεων ακολουθώντας κατανομή νόμου δύναμης. Από τη δεκαετία του 1970 μέχρι σήμερα, το συνολικό κόστος αυξήθηκε κατά μέσο όρο 1,8–6,3 φορές ανά δεκαετία, δημιουργώντας εκτιμώμενο οικονομικό αντίκτυπο της τάξης των 6,09–57,91 δις δολαρίων το χρόνο (για όλα τα κόστη) ή 225,31 εκατομμυρίων-6,84 δις δολαρίων το χρόνο (συνυπολογίζονται μόνο στοιχεία κόστους υψηλής αξιοπιστίας που υλοποιήθηκαν). Το οικονομικό αντίκτυπο που προκύπτει από είδη φυτών ήταν το υψηλότερο συγκριτικά με τα υπόλοιπα βασίλεια (151,68 δις δολάρια), παρόλο που τα περισσότερα κόστη δεν μπορούν να αποδοθούν σε ένα μόνο είδος. Από τα αναγνωρισμένα αγρωστώδη, αυτά με το υψηλότερο οικονομικό αντίκτυπο ήταν η Ήρα (*Lolium rigidum*), το Παρθένιο (*Parthenium hysterophorus*) και το Ιακώβαιο (*Senecio jacobaea*). Οι τέσσερις τάξεις με το υψηλότερο κόστος ήταν τα Θηλαστικά (48,63 δις δολάρια), τα Έντομα (11,95 δις δολάρια), τα Ευδικοτυλήδονα φυτά (4,10 δις δολάρια) και τα Μονοκοτυλήδονα φυτά (1,92 δις δολάρια). Τα τρία είδη με το μεγαλύτερο οικονομικό αντίκτυπο ήταν όλα ζώα — γάτες (*Felis catus*), κουνέλια (*Oryctolagus cuniculus*) και Αμερικάνικα κόκκινα μυρμήγκια (*Solenopsis invicta*). Η σύνθεση των κύριων στοιχείων κόστους ανά είδος ήταν διαφορετική για κάθε πολιτεία/επικράτεια, με τα περισσότερα κόστη (3–62%) ωστόσο να προέρχονται από ένα έως τρία είδη ανά διοικητική μονάδα. Η πλειονότητα (61%) των καταγεγραμμένων στοιχείων κόστους αφορούσε σε πολλαπλά περιβάλλοντα και 73% του συνόλου αυτών αφορούσε σε άμεση βλάβη ή εξαφάνιση, σε σύγκριση με το κόστος διαχείρισης αποκλειστικά, με τα δύο αυτά αποτελέσματα να αντανακλούν την διαθεσιμότητα των δεδομένων. Η αύξηση στην εισαγωγή χωροκατακτητικών ειδών θα συνεχίσει να έχει σημαντικό οικονομικό αντίκτυπο για την Αυστραλιανή οικονομία, αλλά με καλύτερες επενδύσεις, τυποποιημένες αξιολογήσεις και

αναφορές, καθώς και με συντονισμένες παρεμβάσεις (συμπεριλαμβανομένης της εξολόθρευσης), μέρος του κόστους μπορεί να μειωθεί σημαντικά.

Abstract in Japanese

オーストラリアにおける侵入種の経済的影響の包括的な評価
オーストラリアへの侵略的外来種の故意かつ偶発的な導入の余波は多大な経済的犠牲をもたらしたが、直接的な損失と被害、および管理介入に関連する経済的影響（コスト）の大きさを定量化することは、とらえどころのないままである。これは、推定値とアンダーサンプリングの信頼性が決定されていないためである。最近公開されたInvaCostデータベースと補足情報に基づいて、1960年代以降、オーストラリア経済への侵入種に関連して報告されたコストの詳細な分析をはじめて提供し、合計2078の固有のコストエントリを提供することができた。1960年代以降、オーストラリアは、侵入種から少なくとも合計2985.8億米ドル（2017年の価値）あるいは3895.9億豪ドル（2017年の平均為替レート）の損失を費やした。ただし、べき法則に従って見積もりの数が増えるとコストが上がることを考えると、これは過小評価である。1970年代から現在までの10年間の総コストは平均1.8～6.3倍に増加し、推定コストは1年目で60億9千万～57.9億ドル（合計）、1年目で2億2,531万～68.4億ドルになった（観察された、信頼性の高いコストのみ）。植物種から生じる費用は、植物界と動物界の間で最も高かった（1516.8億米ドル）が、費用のほとんどは単一種に起因するものではなかった。同定された雑草種の中で、最も高価なのは、毎年恒例のライグラス（*Lolium rigidum*）、パルテニウム（*Parthenium hysterophorus*）、およびラグワート（*Senecio jacobaea*）だった。最も費用のかかる4つのクラスは、哺乳類（486.3億米ドル）、昆虫（119.5億米ドル）、真正双子類（41.0億米ドル）、単子葉植物（19億2000万米ドル）だった。最も高価な3種は、猫（*Felis catus*）、ウサギ（*Oryctolagus cuniculus*）、ヒアリ（*Solenopsis invicta*）のすべての動物でした。各州/準州には、種ごとに異なる一連の主要なコストがあったが、ほとんど（3～62%）のコストは、政治単位ごとに1～3種に由来していた。報告されたコストのほとんど（61%）は複数の環境に適用され、全体の73%は管理コストのみと比較して直接的な損傷または損失に関連しており、これらの調査結果は両方ともデータの可用性を反映している。侵入種の侵入の増加は、オーストラリア経済にとって引き続きかなりのコストがかかるが、より良い投資、標準化された評価と報告、および調整された介入（根絶を含む）により、これらのコストの一部は大幅に削減される可能性がある。

Abstract in Korean

오스트레일리아의 외래침입종의 경제적 비용에 대한 상세 평가
의도적이거나 우연히 호주로 유입된 외래 침입종은 막대한 경제적 손실을 발생시켰지만, 외래종의 유입으로 인한 직접적인 손실 및 피해와 관련된 직접적인 비용뿐만 아니라 관리 비용 등의 규모는 여전히 수치화되지 못하고 있다. 이는 비용 추정치 및 과소 표집의 신뢰성이 부족하기 때문이다. 우리는 총 2078개의 고유 비용 항목에 대해 최근 발표된 InvaCost 데이터베이스를 기반으로 1960년대 이후 오스트레일리아로 유입된 외래 침입종의 경제 비용에 대한 상세 분석을 진행하였다. 1960년대 이후 오스트레일리아는 외래 침입종으로 인하여 최소 2985억 8천만 달러 (2017년 미화 가치 기준) 또는 3895억 9천만 달러 (2017년 평균 환율 적용한 오스트레일리아화 기준)의 경제적 손실을 보았다. 그러나 추정치의 수가 증가함에 따라 비용이 증가한다는 멱 법칙을 고려하였을 때 이는 과소평가되었다고 볼 수 있다. 1970년대 이후 현재까지 매 10년간 총비용은 1.8 ~ 6.3배 증가하였으며, 추정비용은 연간 미화 609 ~ 579억 (모든 비용을 포함하였을 경우) 혹은 미화 2억 253만 1천 ~ 68억 4천만 (신뢰성이 높은 알려진 비용만 포함한 경우) 달러 수준이다. 연구에 포함된 계 중 식물 종에서 발생한 비용이 가장 높았으나 (미화 1516억 8천만 달러) 단일종 큰 집중적으로 비용을 발생시키지는 않았다. 확인된 잡초종

중에서 가장 큰 비용을 발생시킨 종은 호밀 (*Lolium rigidum*), 파르테늄 (*Parthenium hysterophorus*) and 래그워트 (*Senecio jacobaea*) 등이었다. 강 분류 별로 포유류 (미화 486억 3000만 달러), 곤충 (119억 5천만 달러), 진정쌍떡잎식물 (미화 41억 1천만 달러), 외떡잎식물 (미화 19억 2천만 달러) 등이 가장 큰 비용을 발생시켰다. 종 분류 별로 가장 큰 비용을 발생시킨 종은 고양이 (*Felis catus*), 토끼 (*Oryctolagus cuniculus*), 붉은 불개미 (*Solenopsis invicta*) 등의 동물들이었다. 각각의 주 별로 비용을 발생시킨 주요 종이 다르지만, 대부분 (3 ~ 62%)의 비용은 주별로 1 ~ 3개의 종에 의해서 발생하였다. 보고된 비용의 대부분 (61%) 은 다양한 환경에 적용되었고, 전체 비용의 73%는 관리 비용보다는 직접적인 손실에 관련되어 있으며, 두 결과 모두 데이터의 가용성을 반영한다. 외래 침입종의 유입 증가는 오스트레일리아 경제에 상당한 비용을 부담시킬 것이다. 그러나 적절한 투자와, 표준화된 평가 및 보고 방법, 조직적인 개입 (퇴치 포함)은 이러한 비용을 상당히 감수할 수 있을 것이다.

Abstract in Russian

Подробная оценка фактических экономических потерь от инвазионных видов в Австралии. Наследие осознанной и случайной интродукции инвазионных чужеродных видов в Австралии привело к огромным экономическим потерям, однако же количественные оценки величин экономических потерь, связанных с прямым ущербом, а также с расходами на контроль инвайдеров все еще единичны. Это имеет отношение в том числе и к проблеме надежности оценок и их недостаточности. Мы предоставляем первый подробный анализ фактических экономических потерь от инвазионных видов для австралийской экономики начиная с 1960-х гг., проведенный на основе данных из недавно опубликованной базы данных InvaCost и дополнительной информации; всего было проанализировано 2078 позиций убытков. С 1960-х гг. фактические и прогнозные убытки от инвазионных видов в Австралии в совокупности составили около 298,58 млрд долларов США (по курсу валюты на 2017 г.), или 389,59 млрд австралийских долларов (по среднему обменному курсу на 2017 г.). Однако это заниженная оценка, учитывая тот факт, что величина потерь растет с увеличением числа оценок согласно степенному закону. С 1970-х гг. по настоящее время общие потери увеличивались в среднем в 1,8–6,3 раза за десятилетие, в результате чего предполагаемые потери составили 6,09–57,91 млрд долларов США в год$^{-1}$ (все потери вместе взятые) или от 225,31 млн до 6,84 млрд долларов США в год$^{-1}$ (только фактические высоконадежные оценки). Потери, связанные с чужеродными растениями, были самыми высокими в сравнении с таковыми в разных таксономических царствах (151,68 млрд долларов США), вместе с тем значительная часть экономических потерь не относилась к одному конкретному биологическому виду. Среди сорных растений наибольшие убытки были связаны с райграсом однолетним (*Lolium rigidum*), партенией (*Parthenium hysterophorus*) и крестовником луговым (*Senecio jacobaea*). Значительные потери были вызваны инвазиями представителей четырех таксономических классов: млекопитающих (48,63 млрд долларов США), насекомых (11,95 млрд долларов США), эвдикотов (4,10 млрд долларов США) и однодольных растений (1,92 млрд долларов США). Среди животных наибольший ущерб был отмечен от кошек (*Felis catus*), кроликов (*Oryctolagus cuniculus*) и красных огненных муравьев (*Solenopsis invicta*). Каждый штат или территория характеризовался разными типами потерь от видов-инвайдеров, но большинство потерь (3–62%) приходилось на 1–3 вида-инвайдера на административно-территориальную единицу. Большая часть (61%) экономических потерь была задокументирована для нескольких сред обитания, а 73% от общей суммы убытков относились к прямым потерям или тратам на контроль, что обусловлено наличием таких оценок. Рост инвазий будет продолжать приносить существенные расходы экономике Австралии, но при более эффективных инвестициях, стандартизированных оценках и отчетности, а также скоординированных действиях (включая искоренение видов-инвайдеров) некоторые из этих затрат могут быть существенно сокращены.

Abstract in Arabic

ايلارتسأ يف ةيزاغلا عاونألل اهنع نلعملا ةيداصتقالا فيلاكتلل يليصفت مييقت
ىلإ ىدأ ايلارتسأ ىلإ يضرعلا وأ اهنم دّمعتملا ًءاوس ةبيرغلا ةيزاغلا عاونألا لاخدإ ىدأ :صلختسملا
رارضألاو رئاسخلاب ةطبترملا فيلاكتلا مجح ديدحت لازي الف كلذ عمو ،ةظهاب ةيداصتقا فيلاكت
تاريدقت ةقد ديدحت مدع ىلإ كلذ يف ببسلا دوعيو .قيقحتلا ةديعب ةيرادإلا تالخدتلاو ةرشابملا
ليلحت لوأ مييقتلا اذه يف مدقنو .عاونألا هذه نم تانيعلا ذخأ يف صقنلا كلذكو ةيداصتقالا ةفلكتلا
ةيدالىملا تانيتسلا ذنم يلارتسألا داصتقالل ةيزاغلا عاونألاب ةطبترملاو اهنع نلعملا فيلاكتلل
2078 يلامجإب اهيف ةيليمكتلا تامولعملاو ًارخؤم ةروشنملا InvaCost تانايب ةدعاق ىلع ًءانب كلذو
ةيزاغلا عاونألا هذه نم ةيدالىملا تانيتسلا ذنم ايلارتسأ رئاسخ عومجم تغلب ثيح .درفتم لخدم
389.59 لداعي ام وه و 2017 ماع تانايب ىلع ًءانب لقألا ىلع يكيرمأ رالود رايلم 298.58 براقي ام
نأل ًارظن عقاولا نم لقأ مقرلا اذه دعي كلذ عمو .ماعلا سفنل فرصلا رعس بسح كلذو يلارتسأ رالود
طسوتم ناك ثيح .ةيمسرلا نيناوقلل اقبط تاريدقتلا ددع ةدايز عم عفترت ةيداصتقالا فيلاكتلا
ىتحو ةيدالىملا تاينيعبسلا ذنم دقع لكل فيلاكتلا يلامجإ يف 6.3 ىلإ 1.8 نيب ام حوارتي ةدايزلا
رالود رايلم 57.91 ىلإ 6.09 نيب ام حوارتت ةيريدقت فيلاكت ديدحت ىلإ ىدأ امم ،رضاحلا تقولا
ًايونس يكيرمأ رالود رايلم 6.84 – يكيرمأ رالود نويلم 225.31 وأ (فيلاكتلا ةلمج) ًايونس يكيرمأ
نم ىلعألا يه ةيزاغلا ةيتابنلا عاونألا نع ةئشانلا فيلاكتلا تناك .(ةياغلل ةقوثوم فيلاكت ،ةظوحلم)
مظعم نأ نم مغرلاب يكيرمأ رالود رايلم 151.68 نم براقي ام ةفلكتلا تغلب ثيح ىرخألا عاونألا نيب
تابن اهديدحت مت يتلا باشعألا عاونأ نيب نم ةفلكت ىلعألا تناكو .ددحم عون ىلإ زعُت مل فيلاكتلا
الزوان الشخن السنوي (*Lolium rigidum*) والبارثينيوم (*Parthenium hysterophorus*) وزهرة الشيخ (*Sene-*
cio jacobaea). امك تناك تائفلا ألارع رثكألا ةفلكت ًتشمل الثدييات (48.63 رايلم رالود يكيرمأ)
والحشرات (11.95 رايلم رالود يكيرمأ) وثنائيات الفلقة الحقيقية (4.10 رايلم رالود يكيرمأ)
وأحاديات الفلقة (1.92 رايلم رالود يكيرمأ). وكانت األنواع الثالثة األكثر تكلفة تشمل جميع
الحيوانات كالقطط مثالً (*Felis catus*) واألرانب (*Oryctolagus cuniculus*) والنمل األحمر الناري المستورد
(*Solenopsis invicta*). امك ناك لكل واليةٍ وأ إقليم مجموعة خمتلفة من التكاليف الكبيرة حسب األنواع
الموجودة في هذه الوالية أو اإلقليم ولكن معظم التكاليف (26%- 3) اشتقت من نوع إلى ثالثة أنواع لكل
وحدة سياسية. معظم التكاليف التي بُلغ عنها (61%) تم تطبيقها على بيئات متعددة بينما يتعلق
ما يقارب 73% من إجمالي البالغات بالضرر أو الخسارة المباشرة مقارنةً بالتكاليف اإلدارية فقط.
وكال هاتين النتيجتين تعكسان تفاوت البيانات. وستستمر زيادة األنواع الغازية بشكل متزايد
في المستقبل مما سيحمّل االقتصاد األسترالي تكاليف كبيرة. ولكن يمكن تخفيض بعض هذه
التكاليف بشكلٍ كبير من خالل تحسين االستثمار وتوحيد التقييم لآلثار والتكاليف باإلضافة
إلى تنسيق التدخالت بما في ذلك االستئصال أن لزم األمر.

Abstract in Farsi

ایلارتسا رد یموب ریغ یاهنوگ یداصتقا نایز شرازگ یبایزرا
هتشاد رب رد یداصتقا نیگنس یاهدمایپ ایلارتسا هب یموب ریغ یاه هنوگ یفداصت و یدمع دورو
رد ام .تسا راوشد نآ)لرتنک(نارحب تیریدم نیچمه و نایز و ررض هنیزه دروآرب ،دوجو نیا اب تسا
۱۹۶۰ لاس زا یموب ریغ یاهنوگ دورو زا هدش شرازگ یداصتقا یاههنیزه راب نیلوا یارب هلاقم نیا
یسررب)دشابیم هعلاطم ۲۰۷۸ دادعت لماش هک(تسکوناو یتاعالطا عبنم ساسا ربا ایلارتسا هب
۲۹۸.۵۸ لقادح لداعم یلام ررض لمحتم یموب ریغ یاهنوگ لیلد هب روشک نیا ،۱۹۶۰ لاس زا .میدرک
.تسا هدش)۲۰۱۷ لاس رد رالد خرن باستحا هب(ایلارتسا رالد نویلیب ۳۸۹.۵۹ ای اکیرمآ رالد نویلیب
نیرتالاب .تسا هدش ربارب ۶.۳ ات ۱.۸ طسوتم روط هب اههنیزه نازیم ههد ره رد ،نونک ات ۱۹۷۰ لاس زا
صتخم هچ رگا ،)اکیرمآ رالد نویلیب ۱۵۱.۶۸(تسا یهایگ یاهنوگ هب طوبرم اهلسلس نایم رد هنیزه
،سرگ یار لماش اهنیرت هنیزه رپ ،هدش ییاسانش یفلع یاهنوگ نایم زا .دشاب یمن یصاخ هنوگ هب
،)اکیرمآ رالد نویلیب ۴۸.۶۳(نارادناتسپ لماش هنیزه رپ ُهدر راهچ .دنا هدوب تروگار و مویتنراپ
۱.۹۲(اه یاهپل کت و)اکیرمآ رالد نویلیب ۴.۱۰(اهیا هپل ود ،)اکیرمآ رالد نویلیب ۱۱.۹۵(تارشح
اهشوگرخ ،اههبرگ ـدنا هدوب تاناویح زا یگمه هنیزه رپ ُهنوگ هس .تسا هدوب)اکیرمآ رالد نویلیب
۷۳ و هاگتسیز دنچ هب طوبرم اههنیزه لک دصرد ۶۱ هک تسا هداد ناشن دهاوش .یموب ریغ زمرق یاههچروم

دیکات و)دشاب یمن نارحب تیریدم هنیزه لماش رامآ نیا(دشابیم نایز و ررض هب طوبرم اههنیزه دصرد
هدشن تبث دانسا ساسا رب نآ ریغت ناکما و هدوب هدش تبث دانسا ساسا رب ماقرا نیا هک مینکیم
یاه هنوگ یفداصت و یدمع دورو رطاخ هب ایلارتسا روشک هب یداصتقا نایز و ررض لیمحت .دراد دوجو
داد شهاک ار اههنیزه زا یخرب ناوتیم رتهب یرازگ هیامرس اب یلو ،تشاد دهاوخ همادا یموب ریغ

Abstract in Czech

Podrobné zhodnocení vykázaných ekonomických nákladů způsobených invazivními druhy v Austrálii. Úmyslné i náhodné zavlečení nepůvodních invazních druhů do Austrálie si vyžádalo značné ekonomické náklady. Výše těchto nákladů ve vztahu ke způsobeným škodám a managementu těchto druhů je však do značné míry neznámá. Hlavním důvodem je nedostatečná dostupnost a spolehlivost takovýchto odhadů. Tato studie představuje první podrobnou analýzu vykázaných nákladů způsobených invazními druhy australskému hospodářství od 60. let minulého století. Studie vychází z nedávno zveřejněné databáze InvaCost a doplňujících zdrojů, jenž celkem podchycují 2078 jedinečných záznamů takovýchto nákladů. Od šedesátých let minulého století již vynaložila Austrálie za dopady invazních druhů nejméně 298,6 miliardy amerických dolarů (hodnota pro rok 2017). Tyto náklady jsou však podhodnoceny, jelikož jejich úroveň roste s počtem dostupných odhadů. Od 70. let do současnosti došlo v průměru k 1,8–6,3násobnému nárůstu celkových nákladů za desetiletí, což vedlo k odhadovaným nákladům 6,09–57,91 miliardy amerických dolarů ročně (souhrn všech nákladů) nebo 225,3 milionu až 6,84 miliard amerických dolarů ročně za pozorované, vysoce spolehlivě prokázané náklady. Nejvyšší náklady byly na invazní rostliny (151,7 miliard amerických dolarů), ačkoli jejich většinu nelze přičíst jednomu druhu. Nejvýznamnějšími byli jílek tuhý (*Lolium rigidum*), sambaba obecná (*Parthenium hysterophorus*) a starček přímětník (*Senecio jacobaea*). Čtyřmi nejnákladnějšími třídami byli savci (48,63 miliard amerických dolarů), hmyz (11,95 miliard amerických dolarů), dvouděložné (4,10 miliard amerických dolarů) a jednoděložné rostliny (1,92 miliard amerických dolarů). Třemi nejnákladnější živočichy byla kočka domácí (*Felis catus*), králík divoký (*Oryctolagus cuniculus*) a mravenec (*Solenopsis invicta*). Každý stát/teritorium měl jinou skupinu nejnákladnějších druhů, ale většina (3–62%) nákladů vždy pocházela od jednoho až tří druhů. Většina (61%) vykázaných nákladů se vztahovala k více typům prostředí a 73% z této částky se týkalo přímých škod, na rozdíl od nákladů na management těchto druhů, jak ukazují dostupná data. Počet invazních druhů se bude zvyšovat, což bude mít za následek rostoucí náklady pro australské hospodářství, avšak lepšími investicemi, standardizovaným hodnocením i vykazováním a koordinovanými zásahy (včetně eradikací) lze některé z těchto nákladů podstatně snížit.

Abstract in Polish

Kompleksowa ocena kosztów ekonomicznych gatunków inwazyjnych w Australii. Dziedzictwo celowego i przypadkowego wprowadzenia inwazyjnych gatunków obcych do Australii miało ogromny wpływ na gospodarkę, jakkolwiek wycena wielkości kosztów związanych z bezpośrednimi stratami i szkodami oraz interwencją w zakresie zarządzania, pozostaje nieuchwytna. Wynika to z tego, że nie określono wiarygodności szacunków kosztów i niedostatecznego pobierania próbek. Dostarczamy pierwszej szczegółowej analizy kosztów poniesionych przez australijską gospodarkę, związanych z gatunkami inwazyjnymi, zgłoszonych od 1960 roku. Analiza ta została oparta o niedawno opublikowaną bazę danych InvaCost oraz informacje uzupełniające, w sumie 2078 indywidualnych wpisów kosztów. Od 1960 roku Australia poniosła koszty i straty z powodu gatunków inwazyjnych w łącznej wysokości co najmniej 298,58 mld USD (wartość z 2017 r.), co stanowi rownowartość 389,59 mld AUD (średni kurs wymiany z 2017 r.). Jest to jednak niedoszacowanie, biorąc pod uwagę, że koszty się potęgują wraz ze wzrostem liczby szacunków. Od lat 1970-tych do chwili obecnej nastąpił średnio 1,8–6,3-krotny wzrost całkowitych kosztów na dekadę, co oznacza wzrost szacowanych kosztów w wysokości 6,09–57,91 mld USD rocznie (wszystkie koszty łącznie) lub 225,31 mln–6,84 mld USD rocznie (dotyczące tylko bardzo wiarygodnych kosztów). Koszty związane z gatunkami roślinnymi były najwyższe wśród królestw (151,68 mld USD), chociaż

większość kosztów nie była przypisywana pojedynczym gatunkom. Ze zidentyfikowanych gatunków chwastów najwyższych kosztów przysporzyły życica sztywna (*Lolium rigidum*), partenium ambrozjowate (*Parthenium histerophorus*) i starzec jakubek (*Senecio jacobaea*). Czterema klasami powodującymi najwyższe koszty były ssaki (48,63 mld USD), owady (11,95 mld USD), rośliny dwuliścienne (4,10 mld USD) i jednoliścienne (1,92 mld USD). Trzema gatunkami powodującymi najwyższe koszty były zwierzęta – koty (*Felis catus*), króliki (*Oryctolagus cuniculus*) i mrówki ogniste (*Solenopsis invicta*). Każdy stan/terytorium miał inny zestaw głównych kosztów według gatunków, ale większość tych kosztów (3–62%) pochodziła z jednego do trzech gatunków na jednostkę polityczną. Najwięcej (61%) zgłoszonych kosztów odnosiło się do wielu środowisk, a 73% całkowitej kwoty dotyczyło bezpośrednich szkód lub strat w porównaniu tylko z kosztami zarządzania, przy czym oba te ustalenia odzwierciedlają dostępność danych. Wzrost ilości gatunków inwazyjnych nadal będzie się wiązał ze znacznymi kosztami dla australijskiej gospodarki, ale dzięki zastosowaniu lepszych inwestycji, znormalizowanych ocen i sprawozdawczości oraz skoordynowaniu interwencji (w tym likwidacji), niektóre z tych kosztów mogłyby zostać znacznie zmniejszone.

Abstract in Bosnian/Croatian

Detaljna procjena prijavljenih ekonomskih troškova invazivnih zivotinjski i biljni vrsta u Australiji. Nasljeđe namjernog i slučajnog unošenja invazivnih stranih zivotinjski i biljni vrsta u Australiju imalo je pozamašan ekonomski utjecaj, ali kvantificirajući veličinu troškova povezanih sa izravnim gubicima i štetom, kao troskove za upravljanje intervencije i dalje je nedostižno. Razlog ovoga he zato sto pouzdanost procjena troškova i nedovoljno uzorkovanje nisu utvrđene i standarizovane. Ovdje dajemo prvu detaljnu analizu prijavljenih troškova povezanih s invazivnim zivotinjskim i biljnim vrstama za Australsko gospodarstvo od 1960-ih, na temelju nedavno objavljene baze podataka InvaCost i dodatnih podataka, za ukupno 2078 jedinstvenih unosa troškova. Od šezdesetih godina Australija je od invazivnih zivotinjskin i biljni vrsta potrošila ili pretrpjela gubitke u ukupnom iznosu od najmanje 298,58 milijardi američkih dolara (vrijednost 2017.) ili 389,59 milijardi američkih dolara (prosječni tečaj 2017.). Međutim, ovo je znacajno podcijenjeno s obzirom na to da troškovi rastu kako se broj procjena povećava slijedeći zakonske promjene. Ukupni troškovi po desetljeću od 1970-ih do danas u prosjeku su porasli za 1,8–6,3 puta, što je prouzrokovalo procijenjene troškove od 6,09–57,91 milijardi USD[1] (svi troškovi zajedno) ili 225,31 milijuna– 6,84 milijarde USD[1] (uočeno, samo vrlo pouzdani troškovi). Troškovi biljnih vrsta bili su najveći među kraljevstvima (151,68 milijardi USD), iako se većina troškova nije pripisala jednoj vrsti biljki. Od identificiranih korovitih vrsta biljki najskuplji su bili jednogodišnji ljulj (*Lolium rigidum*), partenij (*Parthenium hysterophorus*) i krpa (*Senecio jacobaea*). Četiri najskuplje klase bili su sisavci (48,63 milijarde USD), insekti (11,95 milijardi USD), eudikoti (4,10 milijardi USD) i monokoti (1,92 milijarde USD). Tri najskuplje vrste bile su sve životinje – mačke (*Felis catus*), zečevi (*Oryctolagus cuniculus*) i crveni uvezeni vatreni mravi (*Solenopsis invicta*). Svaka država / teritorij imala je različit skup glavnih troškova po vrstama, ali s većinom (3–62%) troškova koji proizlaze iz jedne do tri vrste po političkoj jedinici. Većina (61%) prijavljenih troškova odnosila se na više okruženja, a 73% ukupnih troškova odnosilo se na izravnu štetu ili gubitak u usporedbi samo s troškovima upravljanja, s tim da oba ova otkrića directno ovise o dostupnost podataka. Rastući napadi invazivnih zivotinjski i biljni vrsta i dalje će imati značajne troškove za Australsko gospodarstvo, ali boljim ulaganjem, standardiziranim procjenama i izvješćivanjem te koordiniranim intervencijama (uključujući iskorjenjivanje), neki od tih troškova mogli bi se znatno smanjiti u buducnosti.

Abstract in Punjabi

ਆਸਟਰੇਲੀਆ ਵਿਚ ਧਾੜਵੀ ਪ੍ਰਜਾਤੀਆਂ ਦੀਆਂ ਰਪਿੋਰਟ ਕੀਤੀਆਂ ਆਰਥਕਿ ਕੀਮਤਾਂ ਦਾ ਵਸਿਤਰਤਿ ਮੁਲਾਂਕਣ
ਆਸਟਰੇਲੀਆ ਵਿਚ ਗੈਰ-ਮੂਲ ਪਰਦੇਸੀ ਜਾਤੀਆਂ ਦੀ ਜਾਣੇ-ਅਣਜਾਣੇ ਵਿਚ ਕੀਤੀ ਗਈ ਅਸ੍ਥਾਪ੍ਨਾ ਨਾਲ ਭਾਰੀ ਆਰਥਕਿ ਘਾਟਾ ਪਆਿ ਹੈ, ਫਰਿ ਵੀ ਸੱਧਿੇ ਘਾਟੇ ਅਤੇ ਨੁਕਸਾਨ ਦੇ ਨਾਲ-ਨਾਲ ਪ੍ਰਬੰਧਨ ਦੇ ਦਖਲਅੰਦਾਜ਼ੀ ਨਾਲ ਜੁੜੇ ਖਰਚਆਿਂ ਦੀ ਵਆਿਖਆਿ ਮੁਸ਼ਕਲ ਹੈ| ਅਜੇਹਾ ਇਸ ਲਈ ਹੈ ਕਉਿਂਕ ਲਾਗਤ ਦੇ ਅਨੁਮਾਨਾਂ ਅਤੇ ਘੱਟ ਨਮੂਨੇ ਲੈਣ ਦੀ ਭਰੋਸੇਯੋਗਤਾ ਨਰਿਧਾਰਤ ਨਹੀ ਕੀਤੀ ਗਈ ਹੈ| ਅਸੀ ਹਾਲ ਹੀ ਵੱਿਚ ਪ੍ਰਕਾਸ਼ਤ ਇਨਵਾਕੋਸਟ ਡੇਟਾਬੇਸ (InvaCost database) ਅਤੇ

ਪੂਰਕ ਜਾਣਕਾਰੀ ਦੇ ਅਧਾਰ ਤੇ, ਕੁੱਲ 2078 ਵਲਿੱਖਣ ਲਾਗਤ ਐਂਟਰੀਆਂ ਲਈ, 1960 ਤੋਂ ਆਸਟਰੇਲੀਆਈ ਆਰਥਕਿਤਾ ਉੱਤੇ ਧਾੜਵੀ ਪ੍ਰਜਾਤੀਆਂ ਨਾਲ ਜੁੜੀਆਂ ਖਬਰਾਂ ਦਾ ਪਹਲਿਾ ਵਸਿਥਾਰਤ ਵਸ਼ਿਲੇਸ਼ਣ ਪ੍ਰਦਾਨ ਕਰਦੇ ਹਾਂ| 1960ਵਆਿਂ ਤੋਂ ਲੈਕੇ, ਆਸਟਰੇਲੀਆ ਨੇ ਧਾੜਵੀ ਪ੍ਰਜਾਤੀਆਂ ਤੇ ਘੱਟੋ ਘੱਟ 298.58 US ਬਲੀਅਨ ਡਾਲਰ (2017 ਮੁੱਲ) ਜਾਂ 389.59 AU ਬਲੀਅਨ ਡਾਲਰ (2017 ਔਸਤ ਐਕਸਚੇਂਜ ਰੇਟ) ਦਾ ਖਰਚ ਕੀਤਾ ਹੈ ਜਾਂ ਨੁਕਸਾਨ ਪਾਇਆ ਹੈ| ਹਾਲਾਂਕਿ, ਇਹ ਇੱਕ ਘੱਟ ਅੰਦਾਜ਼ਾ ਹੈ ਕਿ ਜਵਿੇਂ ਜਵਿੇਂ ਸ਼ਕਤੀ ਕਾਨੂੰਨ ਦੇ ਬਾਅਦ ਅਨੁਮਾਨਾਂ ਦੀ ਗਣਿਤੀ ਵਧਦੀ ਹੈ, ਲਾਗਤਾਂ ਵੱਿਚ ਵਾਧਾ ਹੁੰਦਾ ਹੈ| 1970 ਵਆਿਂ ਤੋਂ ਲੈ ਕੇ ਹੁਣ ਤੱਕ, ਹਰ ਦਹਾਕੇ ਵੱਿਚ ਕੁਲ ਖਰਚਆਿਂ ਵੱਿਚ ਔਸਤ 1.8–6.3 ਗੁਣਾ ਵਾਧਾ ਹੋਇਆ ਹੈ, ਜੋ ਕਿ 6.09–57.91US ਬਲੀਅਨ ਡਾਲਰ ਪ੍ਰਤੀ ਸਾਲ (ਸਾਰੇ ਖਰਚੇ ਜੋੜ ਕੇ) ਜਾਂ 225.31 ਮਲੀਅਨ – 6.84 US ਬਲੀਅਨ ਡਾਲਰ ਪ੍ਰਤੀ ਸਾਲ (ਨਰੀਖਅਤ, ਸਰਿਫ ਬਹੁਤ ਭਰੋਸੇਮੰਦ ਖਰਚੇ)ਦਾ ਅਨੁਮਾਨਤ ਖਰਚਾ ਸੀ। ਪੌਦਆਿਂ ਦੀਆਂ ਪ੍ਰਜਾਤੀਆਂ ਤੋਂ ਪੈਦਾ ਹੋਣ ਵਾਲੀਆਂ ਲਾਗਤਾਂ ਰਾਜ ਵਚਿ ਸਭ ਤੋਂ ਵੱਧ ਸਨ (151.68 ਬਲੀਅਨ ਡਾਲਰ), ਹਾਲਾਂਕਿ ਜ਼ਆਿਦਾਤਰ ਲਾਗਤਾਂ ਇਕ ਪ੍ਰਜਾਤੀ ਕਰਕੇ ਨਹੀਂ ਸਨ| ਨਦੀਨਾਂ ਦੀ ਪਛਾਣ ਕੀਤੀ ਪ੍ਰਜਾਤੀਆਂ ਵਚੋਂ, ਸਭ ਤੋਂ ਮਹਗਿੀਆਂ ਸਨ ਸਾਲਾਨਾ ਰਾਈਗ੍ਰਾਸ (ਲੋਲੀਅਮ ਰਜਿਡਿਮ), ਪਾਰਥੀਨੀਅਮ (ਪਾਰਥੀਨੀਅਮ ਹਸਿਟੇਰੋਫੋਰਸ) ਅਤੇ ਰੈਗਵੌਰਟ (ਸੇਨੇਸੀਓ ਜਾਕੋਬੀਆ)| ਚਾਰ ਸਭ ਤੋਂ ਮਹਗਿੀਆਂ ਸ਼੍ਰੇਣੀਆਂ ਥਣਧਾਰੀਆਂ (48.63 ਬਲੀਅਨ ਡਾਲਰ), ਕੀੜੇ (11.95 ਬਲੀਅਨ ਡਾਲਰ), ਖੁਡਕਿੋਟਸ (4.10 ਬਲੀਅਨ ਡਾਲਰ) ਅਤੇ ਮੋਨੋਕੋਟਸ (1.92 ਬਲੀਅਨ ਡਾਲਰ) ਸਨ। ਤੀਨ ਮਹਗਿੀਆਂ ਪ੍ਰਜਾਤੀਆਂ ਸਨ – ਬੱਿਲੀਆਂ (ਫੇਲਸਿ ਕੈਟਸ), ਖਰਗੋਸ਼ (ਓਰੀਕਟੋਲਾਗਸ ਕਨਕਿੁਲਸ) ਅਤੇ ਲਾਲ ਆਯਾਤ ਕੀਤੀ ਅੱਗ ਕੀੜੀਆਂ (ਸੋਲੇਨੋਪਸਸਿ ਇਨਵਕਿਟਾ)| ਹਰੇਕ ਰਾਜ / ਖੇਤਰ ਵੱਿਚ ਪ੍ਰਜਾਤੀਆਂ ਦੁਆਰਾ ਵੱਡੇ ਖਰਚਆਿਂ ਦਾ ਵੱਖਰਾ ਸਮੂਹ ਸੀ, ਪਰ ਪ੍ਰਤੀ ਰਾਜਨੀਤਕਿ ਇਕਾਈ ਵਚਿ ਜ਼ਆਿਦਾਤਰ (3–62%), ਇਕ ਤੋਂ ਤੀਨ ਪ੍ਰਜਾਤੀਆਂ ਲਈ ਖਰਚਾ ਕੀਤਾ ਜਾਂਦਾ ਸੀ| ਰਪਿੋਰਟ ਕੀਤੇ ਖਰਚਆਿਂ ਵਚੋਂ ਜ਼ਆਿਦਾਤਰ (61%) ਬਹੁਤੇ ਵਾਤਾਵਰਣ ਤੇ ਲਾਗੂ ਹੁੰਦੇ ਹਨ ਅਤੇ ਕੁੱਲ ਦਾ 73% ਕੇਵਲ ਪ੍ਰਬੰਧਨ ਖਰਚਆਿਂ ਦੇ ਮੁਕਾਬਲੇ ਸੱਿਧੇ ਨੁਕਸਾਨ ਜਾਂ ਘਾਟੇ ਨਾਲ ਸਬੰਧਤ ਹੈ, ਜਦਕਿ ਇਹ ਦੋਵੇਂ ਖੋਜਾਂ ਅੰਕੜਆਿਂ ਦੀ ਉਪਲਬਧਤਾ ਨੂੰ ਦਰਸ਼ਾਉਂਦੀਆਂ ਹਨ| ਧਾੜਵੀ ਪ੍ਰਜਾਤੀਆਂ ਦੇ ਵੱਧ ਰਹੇ ਹਮਲਆਿਂ ਦੇ ਖਰਚਆਿਂ ਦਾ ਭਾਰ ਆਸਟਰੇਲੀਆਈ ਆਰਥਕਿਤਾ ਤੇ ਜਾਰੀ ਰਹੇਗਾ, ਪਰ ਬਹਿਤਰ ਨਵਿੇਸ਼, ਮਆਿਰੀਕਰਨ ਕੀਤੇ ਮੁਲਾਂਕਣਾਂ ਅਤੇ ਰਪਿੋਰਟ ਕਰਨ ਅਤੇ ਤਾਲਮੇਲ ਵਾਲੀਆਂ ਦਖਲਅੰਦਾਜ਼ੀਆਂ (ਖਾਤਮੇ ਸਮੇਤ) ਨਾਲ, ਇਹਨਾਂ ਵੱਿਚੋਂ ਕੁਝ ਖਰਚਆਿਂ ਨੂੰ ਕਾਫ਼ੀ ਹੱਦ ਤੱਕ ਘਟਾਇਆ ਜਾ ਸਕਦਾ ਹੈ|

Abstract in Gujarati

ઓસ્ટ્રેલયિામાં નોંધાયેલ આક્રમક પ્રજાતઓિના આર્થકિ ખર્ચનું વગિતવાર મૂલ્યાંકન

ઓસ્ટ્રેલયિાને આક્રમક પરપ્રાંતીય પ્રજાતઓિના ઇરાદાપૂર્વક અને આકસ્મકિ પ્રવેશના લીધે ભારે આર્થકિ નુકસાન થયું છે. તેમ છતાંય સીધા નુકસાન અને નુકસાન સાથે સંકળાયેલા ખર્ચની મર્યાદા તેમજ વ્યવસ્થાપન દરમયિાનગીરીઓનો અંદાજ લગાવવો હંમેશા મુશ્કેલ રહ્યો છે. જેનું મુખ્ય કારણ વશ્વિસનીય ખર્ચ અંદાજ અને નમૂનાઓની સાપેક્ષતા છે. અમે આ સાથે ઇનવાકોસ્ટ ડાટાબેઝ અને પૂરક માહતિીમાંથી કુલ ૨૦૭૮ નોંધણીઓના આધારે ૧૯૬૦ના દાયકાથી ઓસ્ટ્રેલયિાના આક્રમક પ્રજાતઓિ સાથે સંકળાયેલા ખર્ચની ઓસ્ટ્રલયિાના અર્થતંત્ર પરની અસરનું પ્રથમ વગિતવાર વશ્લિેષણ પ્રસ્તુત કરીએ છીએ. ઓસ્ટ્રેલયિાને ૧૯૬૦ના દાયકાથી આક્રમક પ્રજાતઓિ પાછળ ઓછામાં ઓછું ૨૯૮.૫૮ અબજ અમેરીકન ડોલર (વર્ષ ૨૦૧૭ની કમિત પ્રમાણે) અથવા ૩૮૯.૫૮ (વર્ષ ૨૦૧૭નો સરેરાશ વનિમિયદર પ્રમાણે) અબજ ઓસ્ટ્રેલયિન ડોલરનો કુલ ખર્ચ અથવા નુકસાન થયુ છે. જોકે, આ એક નીચો અંદાજ છે કારણકે ઘાતાંકના નયિમ પ્રમાણે વધતા ખર્ચના લીધે અંદાજમાં વધારો થાય છે. વર્ષ ૧૯૭૦થી અત્યાર સુધી પ્રત્યેક દાયકા દીઠ કુલ સરેરાશ ખર્ચમાં ૧.૮ થી ૬.૩ ગણા વધારાના લીધે વાર્ષકિ અંદાજતિ ખર્ચની મર્યાદા ૬૦.૯ થી ૫૭.૯૧ અબજ અમેરીકન ડોલર પ્રતવિર્ષ (તમામ ખર્ચ સંયુક્ત) અથવા ૨૨.૫૩૧ કરોડ થી ૬.૮૪ અબજ અમેરીકન ડોલર પ્રતવિર્ષ (અવલોકન, માત્ર ખુબ જ વશ્વિસનીય ખર્ચ) અંકાઇ છે. વનસ્પતપ્રિજાતઓિથી થયેલ ખર્ચ સૌથી વધુ હતો (૧૫૧.૬૮ અબજ અમેરીકન ડોલર), જો કે મોટાભાગના ખર્ચ કોઇ એક પ્રજાતનિે આભારી ન હતા. જાણીતી નીદણ પ્રજાતઓિ પૈકી સૌથી ખર્ચાળ રાયગ્રાસ (લોલીયમ રગિડિમ), પાર્થેનયિમ (પાર્થેનયિ હસ્ટિરોફોરસ) અને રાગવોર્ટ (સેનેસઓિ જેકોબીયા) હતા. ચાર સૌથી ખર્ચાળ વર્ગોમાં, સસ્તન પ્રાણીઓ (૪૮.૬૩ અબજ અમેરીકન ડોલર), જંતુઓ/કટિકો (૧૧.૯૫ અબજ અમેરીકન ડોલર), ચુડકોિટ્સ (૪.૧૦ અબજ અમેરીકન ડોલર) અને એકદળીય વનસ્પત (૧.૯૨ અબજ અમેરીકન ડોલર) હતા. ત્રણ સૌથી ખર્ચાળ પ્રજાતઓિમાં બધા જ પ્રાણીઓ હતા – બલિાડીઓ (ફેલસિ કેટસ), સસલા (ઓરીકટોલાગસ ક્યુનીક્યુલસ) અને લાલ આયાતી ફાયર કીડીઓ (સોલેનોપસીસ ઈનવકિટા) હતા. દરેક રાજ્ય/પ્રદેશોમાં પ્રજાતદીઠ ખર્ચ અલગ અલગ હતા. પરંતુ રાજકીય એકમ દીઠ મોટા ભાગનો (૩–૬૨%) ના ખર્ચ એકથી ત્રણ પ્રજાતઓિમાંથી તારવેલ હતો. મોટાભાગના નોંધાયેલ ખર્ચ (૬૧%) વવિધિ પર્યાવરણ અને કુલ ખર્ચના ૭૩%, સીધા નુકશાન અને વ્યવસ્થાપન દરમયિાનગીરીઓનો હતો. આ બંને તારણો માહતિીની ઉપલબ્ધતા દર્શાવે છે. આક્રમક પ્રજાતઓિના વધતા જતા આક્રમણથી ઓસ્ટ્રેલયિન

અર્થતંત્રના ખર્ચમાં નોંધપાત્ર વધારો થતો રહેશે. પરંતુ વધુ સારૂં રોકાણ, પ્રમાણિત આકારણી અને અહેવાલ તથા સંકલિત હસ્તક્ષેપ (નાબૂદી સહિત) ની સહાયથી આ ખર્ચમાં નોંધપાત્ર ઘટાડો થઈ શકે છે.

Abstract in Telugu

ఆస్ట్రేలియాలో ఆక్రమణ మొక్కలు మరియు జంతు జాతుల నివేదించబడిన ఆర్థిక ఖర్చుల వివరణాత్మక పరిశీలన

ఆస్ట్రేలియాకు ఉద్దేశపూర్వకంగా మరియు అనుకోకుండా ఆక్రమణ మొక్కలు మరియు జంతు జాతులను తీసుకొనిరావడంతో ఆస్ట్రేలియాకు భారీ ఆర్థిక నష్టాన్ని కలిగిస్తున్నాయి, ఇంకా ప్రత్యక్ష నష్టం మరియు నష్టంతో సంబంధం ఉన్న ఖర్చుల పరిమాణాన్ని లెక్కించడం, అలాగే నిర్వహణ జోక్యాల ఖర్చు కూడా అస్పష్టంగానే ఉంది. ఎందుకంటే ఖర్చు అంచనాల విశ్వసనీయత మరియు అండర్-శాంప్లింగ్ ఇంకా నిర్ణయించబడలేదు. 1960 ల నుండి ఆస్ట్రేలియన్ ఆర్థిక వ్యవస్థకు ఆక్రమణ మొక్కలు మరియు జంతు జాతులతో సంబంధం ఉన్న నివేదించబడిన ఖర్చుల యొక్క మొదటి వివరణాత్మక విశ్లేషణను మేము అందిస్తున్నాము, ఇది మొత్తం 2078 ప్రత్యేక ఖర్చుల ఎంట్రీల కోసం ఇటీవల ప్రచురించిన ఇన్వాకోస్ట్ డేటాబేస్ (InvaCost Database) మరియు అనుబంధ సమాచారం ఆధారంగా రూపొందించబడింది. 1960 ల నుండి, ఆస్ట్రేలియా ఆక్రమణ మొక్కలు మరియు జంతు జాతుల నుండి కనీసం US $ 298.58 బిలియన్ (2017 విలువ) లేదా AU $ 389.59 బిలియన్ (2017 సగటు మార్పిడి రేటు) మొత్తం నష్టపరిచింది. ఏది ఏమైనా, ఇది తక్కువ అంచనా, గణాంక శక్తి చట్టాన్ని (*a statistical power law*) అనుసరించి అంచనాల సంఖ్య పెరిగేకొద్దీ ఖర్చులు పెరుగుతాయి, 1970 నుండి ఇప్పటి వరకు ప్రతి దశాబ్దానికి మొత్తం ఖర్చులు సగటున 1.8–6.3 రెట్లు పెరిగాయి, అంచనా ఖర్చులు US $ 6.09–57.91 బిలియన్ ఒక సంవత్సరం కి (అన్ని ఖర్చులు కలిపి) లేదా US $ 225.31 మిలియన్ – 6.84 బిలియన్ ఒక సంవత్సరం కి (గమనించబడింది, అత్యంత నమ్మదగిన ఖర్చులు మాత్రమే). మొక్కల జాతుల నుండి ఉత్పన్నమయ్యే ఖర్చులు అత్యధికంగా ఉన్నాయి (US $ 151.68 బిలియన్), అయినప్పటికీ చాలా ఖర్చులు ఒకే మొక్కజాతికి ఆపాదించబడవు. గుర్తించిన కలుపు జాతులలో, ఖరీదైనవి వార్షిక రైగ్రాస్ (*Lolium rigidum*), పార్థేనియం (*Parthenium hysterophorus*) మరియు రాగ్వోర్ట్ (*Senecio jacobaea*). నాలుగు ఖరీదైన తరగతులు క్షీరదాలు (పాలిచ్చు జంతుమలు) (US $ 48.63 బిలియన్), కీటకాలు (US $ 11.95 బిలియన్), డైకాట్స్ (US $ 4.10 బిలియన్) మరియు మోనోకట్స్ (US $ 1.92 బిలియన్). మూడు ఖరీదైన జంతుమల జాతులు – పిల్లులు (*Felis catus*), కుందేళ్ళు (*Oryctolagus cuniculus*) మరియు దిగుమతి చేసుకున్న ఎరుపు అగ్ని చీమలు (*Solenopsis invicta*). ప్రతి రాష్ట్రం (లేదా భూభాగం) జాతుల వారీగా వేర్వేరు ఖర్చులు అంచనాలను వేశారు, అయితే చాలా (3–62%) ఖర్చులు ప్రతి రాష్ట్రం (లేదా భూభాగం) ఒకటి నుండి మూడు జాతుల వరకు తీసుకోబడ్డాయి. నివేదించబడిన ఖర్చులలో ఎక్కువ (61%) బహుళ వాతావరణాలకు వర్తింపజేయబడ్డాయి మరియు మొత్తం 73% నిర్వహణ ఖర్చులతో పోలిస్తే ప్రత్యక్ష నష్టం లేదా నష్టానికి సంబంధించినవి, ఈ రెండు ఫలితాలు డేటా లభ్యతను ప్రతిబింబిస్తాయి. ఆక్రమణ జాతుల పెరుగుతున్న ప్రవేశం ఆస్ట్రేలియన్ ఆర్థిక వ్యవస్థకు చాలా ఖర్చులను కలిగిస్తాయి, అయితే మంచి పెట్టుబడి, ప్రామాణిక అంచనాలు మరియు రిపోర్టింగ్ మరియు సమన్వయ జోక్యాలతో (నిర్మూలనతో సహా), కొన్ని ఈ ఖర్చులు గణనీయంగా తగ్గించబడతాయి.

Abstract in Sinhala

ඕස්ට්‍රේලියාවේ පැතිරී තිබෙන ආක්‍රමණශීලී ශාක හේතුවෙන් සිදුව ඇති ආර්ථික හානිය පිලිබඳ විස්තරාත්මක ඇගයීමක්

සිතාමතා සහ අත්වැරදම් තුලින් ඕස්ට්‍රේලියාවට හඳුන්වා දී ඇති පිටස්තර ශාක සහ සත්ව විශේෂ හේතුවෙන් සිදුව ඇති අති විශාල ආර්ථික හානිය විවිධාකාර වේ. ඍජු සහ වක්‍රව සිදුව ඇති හානි, එනිසා සිදුවන පාලන කටයුතු වෙනුවෙන් යන වියදම සහ එතුලින් මතුව ඇති ප්‍රශ්ණ විසඳීම සඳහා මැදිහත් වීමට සිදුවම වෙනුවෙන් වන

වැය මේ දක්වා නිවැරදිව සහ ප්‍රමාණාත්මකව ගණනය කිරීමක් සිදු නොවීම හේතුවෙන් ඒ පිළිබඳව පැහැදිලි අවබෝධයක් නොමැත. එයට ප්‍රධානතම හේතු වශයෙන් දැක්විය හැක්කේ විශ්වාසදායී ඇගයීම් සහ නියැදි එකතු කිරීමේ ක්‍රමයක් තවම තීරණය කර නොතිබීමයි. මෙහි අපි විස්තරාත්මක ඇගයීමක් සමග ආක්‍රමණික ශාක සහ සත්ව විශේෂ වලින් ඕස්ට්‍රේලියානු ආර්ථිකයට 1960 දශකයේ සිට මේ දක්වා වී ඇති හානිය වාර්තා කරමු. මේ සඳහා Invacost දත්ත සහ සහායක තොරතුරු භාවිත කර ඇත. 1960 දශකයේ සිට ඇමරිකානු ඩොලර් බිලියන 389.59 (2017) පමණ ආර්ථික හානියක් ආක්‍රමණික ශාක සහ සත්ව විශේෂ වලින් සිදුව ඇත.මෙයෙද අවතක්සේරුවකි. හානිය 1.8 – සිට 6.3 ගුනයකින් වැඩිවීමක් දශකයකට වී ඇති බව 1970 සිට මේ දක්වා දක්නට ඇති අතර ඇස්තමේන්තු අගය වසරකට ඇමරිකානු ඩොලර් බිලියන 6.09–57.91 (සියලු වියදම්) හෝ ඇමරිකානු ඩොලර් මිලියන 225.31–6.84 බිලියන (නිරීක්ෂණය වී ඇති විශ්වාසදායී) වී ඇත. ශාක වලින් සිදුවූ හානිය ඉහලම අගයක් වන අතර (ඇමරිකානු ඩොලර් බිලියන 151.68) එක් විශේෂයකට පමනක් මෙයෙ සීමාවී නැත. හඳුනාගත් වල් පැළ අතර වැඩිම වියදම වාර්ෂික රයිග්‍රාස් (*Lolium rigidum*), *parthenium* (*Par thenium hysterophorus*) සහ රැග්වෝට් (*Senecio jacobaea*). සතුන් අතරින් වැඩිම ආර්ථික අලාභය වී ඇත්තේ ක්ෂීරපායීන් ගනේ වන අතර (ඇමරිකු ඩොලර් බිලියන 48.63), කෘමීන් (බිලියන 11.95) ද්විබීජ පත්‍ර (බිලියන 4.10) සහ ඒකබීජ පත්‍ර (බිලියන 1.92) වැඩිම වියදමක් දැරූ විශේෂ තුන වනුයේ පූසන් (*Felis catus*) හාවන් (*Oryctolagus cuniculus*) සහ රතු කුහුඹුවන් (*Solenopsis invicta*) ගනෙි. එක් එක් පළාත් වලට අනුව මෙයෙ වෙනස් විය හැකි වුවද 3% – 6%ක් පමණ වියදම වී ඇත්තේ විශේෂ 1–3 එක් ප්‍රදේශයකට ලෙසයි.61% පමණ වාර්තා වී ඇති හානිය විවිධ පරිසර වලට වන අතර සහ 73% වී ඇත්තේය සෘජු හානිය හෝ ඒවා පාලනය කිරීම සඳහා වූ වියදමයි. වැඩිවන ආක්‍රමණික විශේෂ ඕස්ට්‍රේලියානු ආර්ථකයට බරපතල හානියක් කරයි.නමුත් ප්‍රමිතිගත ඇගයීම්, වාර්තා කිරීම් සහ සංවිධානාත්මක මැදිහත්වීම් තුලින් මේ ආර්ථික හානිය සැලකිය යුතු ලෙසෙ පියවා ගත හැක.

Abstract in Hindi

ऑस्ट्रेलयिा में आक्रामक प्रजातयिों की प्रकाशति आर्थकि लागत का वसि्तृत मूल्यांकन

तेज़ीसे फैलने वाली वदिशी प्रजातयिों का आकस्मकि और असावधानी से कयि गये आयात के फलस्वरूप आस्ट्रेलयिा को भारी आर्थकि नुकसान उठाना पड़ा है। फलिहाल प्रत्यक्ष नुकसान, क्षतएिवं प्रबंधन-उपायों का हानर्निर्धारण कठनि है। लागत अनुमानों और नमूने लेने कप्रि्रकयि की वशि्वसनीयता का उचति आंकलन न कयिा कयिा जाना इसका मुख्य कारण है। हम हाल ही में प्रकाशति हुए इनोवाकोस्ट आंकड़ासंचय (डेटाबेस) और पूरक जानकारी से प्राप्त कुल २०७८ अद्वतिीय लागत प्रवष्टियिों के आधार पर ऑस्ट्रेलयिाई अर्थव्यवस्था के लएि १९६० के बाद से आक्रामक प्रजातयिों के साथ जुड़े आख्या की लागत का पहला वस्तितृत वश्लिेषण प्रदान करते हैं। १९६० के दशक के बाद से, ऑस्ट्रेलयिा ने आक्रामक प्रजातयिों के कारण कम से कम कुल यू.एस. डॉलर २९८.५८ बलियिन (२०१७ मूल्य) या ऑस्ट्रेलयिाई डॉलर ३८९.५९ बलियिन (२०१७ औसत वनिमिय दर) नुकसान या खर्च कयिा है। हालाँकि, यह एक कम अंदाजा है क्योंकी घात के नयिम अनुसार बढ़ते खर्च से अनुमान की सखंया में बढ़ोतरी होती है। १९७० से वर्तमान तक की कुल लागतों में प्रतदिशक कुल औसतन १.८–६.३ गुना वृद्धकि कारण अनुमानति लागत की सीमाएं परसिर यू.एस. डॉलर ६.०९–५७.९१ बलियिन प्रतविर्ष (सभी संयुक्त लागत) या यू.एस. डॉलर २२५.31 मलियिन – ६.८४ बलियिन प्रतविर्ष हुई (अवलोकति, केवल अत्यधकि वशि्वसनीय लागत)। पौधों की प्रजातयिों से उत्पन्न होने वाली लागत जातयिों में सबसे अधकि थी (यू.एस. डॉलर १५१.६८ बलियिन), हालांकएिकल प्रजातअिधकिांश लागत के लएि जम्मिेदार नहीं थीं। पहचान की गई खरपतवार प्रजातयिों में से, सबसे महंगा वार्षकि राईग्रास (लोलयिम रगिडिम), पार्थेनयिम (पार्थेनयिम हस्टिेरोफोरस) और रैगवॉर्ट (सेनेसओि जेकोबयिा) थे। चार महंगे वर्ग स्तनधारी (यू. एस. डॉलर ४८.६३ बलियिन), कीड़े (यू.एस. डॉलर ११.९५ बलियिन), यूडकिोट्स (यू.एस. डॉलर ४.१० बलियिन) और एकबीजपत्री (यू.एस. डॉलर १.९२ बलियिन) थे। तीन महंगी प्रजातयिों में सभी जानवर थे – बलि्लयिां (फेलसि कैटस), खरगोश (ओरीक्टोलैगस क्यूनकिुलस) और लाल आयातति आग चींटी (सोलेनोप्ससि इनवक्टिा)। प्रत्येक राज्य / क्षेत्र में प्रजातयिों द्वारा प्रमुख लागतों का एक अलग समूह था, लेकनि प्रतरिाजनीतकि इकाई में अधकिांश (३–६२%) लागत एक से तीन प्रजातयिों से प्राप्त हुई थी। प्रकाशति की गई अधकिांश लागतों (६१%) ववििधि परस्तिथयिों को लागु पडते है और कुल लागत का ७३%, प्रबंधन दरमयािनगरियिो की तुलना में, प्रत्यक्ष क्षतयिा हानसि संबंधति था, यह दो तारणो माहतिी की उपलब्धता भी दर्शाते है। आक्रामक प्रजातयिों की बढ़ती घटनाओं से ऑस्ट्रेलयिाई अर्थव्यवस्था पर भारी लागत जारी रहेगी, लेकनि बेहतर नवशि, मानकीकृत आकलन और प्रतवदिन और समन्वति दखल (उन्मूलन सहति) के सहाय से इनमें से कुछ लागतों को काफी हद तक कम कयिा जा सकता है।

Keywords
Ecosystem management expenditure, InvaCost, monetary impacts, non-native species, Oceania, socio-economic damage

Introduction

Biological invasions continue to erode economies, ecosystems and societies worldwide, with no sign of abatement (Simberloff et al. 2013; Bradshaw et al. 2016; Pyšek et al. 2020). As the rate of introductions of invasive alien species accelerates given an increasingly connected world (Seebens et al. 2017), the extent and magnitude of these impacts will *ipso facto* also increase. While in recent decades, much research has examined the ecological effects of invasive species across habitat types, geographic regions and taxonomic groups (Crystal-Ornelas and Lockwood 2020, and references therein), quantification of the economic impacts has remained diffuse. In particular, a lack of resolute, comprehensive and synthesised economic cost estimates precludes adequate comparisons and compilation at, for example, the national level. Such information can help to assist in setting priorities by policy-makers and organisations for managing invasive species in some of the most impacted countries.

Recently, the InvaCost database was developed to provide the most comprehensive and standardised compilation of invasion costs globally (Diagne et al. 2020b). This advance now addresses the aforementioned limitations by presenting economic costs at a global scale, yet with sufficient resolution to enable assessment in more granular national, taxonomic and socioeconomic contexts. Further, InvaCost allows for assessment of the reliability of cost estimates, as well as for whether costs are predicted to occur or have been empirically observed. While broad-scale perspectives of the economic costs of invasive species are needed because of the transboundary nature of invasions, national or regional assessments are still required in much greater detail (Diagne et al. 2020a).

Australia – the sixth largest country (7,688,287 km^2) and thirteenth largest economy (2017 gross domestic product = US$1.23 trillion; worldbank.org) in the world, as well as the only true 'island' continent apart from Antarctica – has a long history of deliberate and accidental introductions of invasive species (Hoffmann and Broadhurst 2016). Introductions by humans go back as far as 5,000–10,000 years with the deliberate introduction of the dingo (*Canis dingo*) (Smith et al. 2019) and, today, many different alien species occupy almost every terrestrial, freshwater and marine habitat in the country. Indeed, some of the most infamous international examples of deleterious invasive species are Australian – cane toads (*Rhinella marina*) (Lever 2001), prickly pear cactus (*Opuntia* spp.) (Freeman 1992), swamp buffalo (*Bubalus bubalis*) (Ridpath and Waithman 1988), foxes (*Vulpes vulpes*) (Saunders et al. 2010) and European rabbits (*Oryctolagus cuniculus*) – to name a few. While there have been some successes in suppressing various alien species using biological control and corresponding savings in averted damage, such as the prickly pear cactus (Raghu and Walton 2007) and European rabbits (Cooke et al. 2013), most invasive species represent major ongoing ecological, agricultural and economic problems for the country.

While there have been previous attempts to evaluate the costs of invasive species to the Australian economy, these have either focussed on one or only a few taxa, or have been restricted to particular regions. Only the impacts of invasive plants have been the subject of analyses at the kingdom level (e.g., Sinden et al. 2004). Moreover, most assessments have been reliant on flawed assumptions (Sagoff 2008; Holmes et al. 2009) and extrapolations (Pimentel et al. 2001) or have applied more top-down approaches to estimate costs by sector, rather than to divide the estimates among species, regions, sectors or decades (McLeod 2004; Sinden et al. 2004; Gong et al. 2009; Hoffmann and Broadhurst 2016; Llewellyn et al. 2016).

Here we focus on Australia and its territories to provide the first detailed assessment of the reported economic costs of invasive species since the 1960s, based on records extracted from the recently published InvaCost database (Diagne et al. 2020b), combined with both an independent database of costs restricted to invasive herbivore species (previously unpublished) and recent data describing the costs of invasive plants and other disease-causing agents. Our aims are to (*i*) assess the reliability (values based on actual measures as opposed to non-sourced estimates) of the Australian cost estimates, as has been done previously for invasive insects (Bradshaw et al. 2016) and invasive species globally (Diagne et al. 2021), (*ii*) provide a State/Territory summary of those costs, (*iii*) identify the costliest species nationally and by State/Territory, (*iv*) investigate the most impacted environments and sectors and (*v*) estimate robust temporal trends in the economic costs of invasive species over the last five decades.

Methods

Data collection

To determine the cost of invasive species to the Australian economy, we used cost data collected in the InvaCost database (Diagne et al. 2020a, b) (n = 2,419 entries) concerning the global costs of invasive species, based on published literature, enabling comprehensive quantification of costs associated with invasive species at various spatio-temporal scales. Of these, 877 (36%) entries pertained to Australia. The data in InvaCost were collected following a series of literature searches using the Web of Science platform (webofknowledge.com), Google Scholar (scholar.google.com) and the Google search engine (google.com) and all the retrieved costs were converted to a common, up-to-date currency (2017 US$; data.worldbank.org).

We complemented the InvaCost data in three ways. We first added supplementary cost data from new references containing cost information (~ 2300 entries; https://doi.org/10.6084/m9.figshare.12928145). Next, we added data from the "Costs of Invasive Herbivores in Australia" database compiled by Biosecurity South Australia in 2018. The latter is an unpublished database compiled by L.A. to collate peer-reviewed and government documents reporting estimated costs specifically for 'invasive' herbivores [this can include native species, which compete with human

interests in some cases – for example, kangaroos (various species, notably *Osphranter* and *Macropus* spp.)]. That database also includes pigs (*Sus scrofa*) and birds, even though these species are not all strictly herbivores. Based on the top five commodities in each of the categories of livestock, crops and horticulture as a starting point, the impacts from pest animals on those commodities were compiled for each. Estimates were identified using Google Scholar and Google search engine for peer-reviewed papers, conference papers, surveys and reports (e.g. Australian Bureau of Agricultural and Resource Economics, Invasive Animals Cooperative Research Centre, government and industry reports).

As a last step, we augmented the database with additional, missing cost estimates identified during the review process, as well as additional searching. We included all new costs following the structure, decision points and rules of the original InvaCost data (Diagne et al. 2020b). Many of the additional costs were derived from a single, large report on weeds of cropping systems by Llewellyn et al. (2016). The reporting units used in that report were the Grain Research and Development Corporation agroecological zones and some of these zones crossed state-government boundaries. To assign costs to the State level where an agroecological zone crossed State boundaries, we assumed that costs were evenly distributed across each zone and divided the reported costs proportionally into their respective States. Furthermore, Llewellyn et al. (2016) reported the annual ongoing costs of weed management and these costs were updated by McLeod (2018) for the year 2018 and onwards. To avoid double counting these costs, we extended the Llewellyn et al. (2016) costs up to 2017 and used McLeod (2018) from 2018 onwards. These added costs included new estimates that included the present year (2020). At the time of writing, there were no exchange rates or consumer price index data available from the chosen InvaCost sources. As such, we used an 11-month average (Jan–Nov 2020) exchange rate taken from rba.gov.au/statistics/historical-data.html. We calculated the relevant consumer price index by taking the 12-month average change to November 2020 reported at bls.gov and applied it to the 2019 consumer price index reported by the chosen InvaCost data source (data.worldbank.org).

We reviewed all sources, as well as the references they cited, to identify additional sources. Each entry recorded: (*i*) species identity ('general' if unspecified); (*ii*) reported cost (including range if available; no hypothetical costs included); (*iii*) jurisdiction (including area of coverage if provided); (*iv*) applicable year(s) (set to year of publication if not provided); (*v*) implementation (observed or extrapolated); (*vi*) method (field, desktop, both); (*vii*) verification (whether approach could be identified/repeated); and (*viii*) type (control, loss, research, damage, mixed).

After combining the separate databases and standardising/aligning columns, we removed obvious duplicate cost estimates (i.e. same cost figures from (non-)identical sources) following previous protocols (Bradshaw et al. 2016; Diagne et al. 2020b). Following our data processing (see below), we finished with a total of $n = 2257$ unique entries pertaining to Australia for analysis (database available for download at https://doi.org/10.5281/zenodo.4455979).

Estimating total costs

Deriving the total cumulative costs of the impacts and management of invasive species over time requires considering the temporal period to which a particular cost estimate applies. We calculated the duration of a cost as the number of years between the probable start and end years provided in the full database. When the exact start year was unknown, we conservatively considered the year of publication of a primary data source as either the start year or the end year, to which the duration (if mentioned) in number of years was considered (by adding or subtracting the number of years) to derive either, respectively, the end or the start year (Diagne et al. 2020b). We did not use data describing costs prior to 1960 to avoid inconsistencies in currency conversion. We also removed all costs identified as 'avoided' because of a given intervention (i.e. unrealised costs).

To calculate the total cumulative cost, we first recalculated all the annual costs for the defined periods of their occurrence using the `invacost` package in R via the *expandYearlyCosts* function (Leroy et al. 2020) and then summed them to obtain total costs. We also estimated the invasion costs for a series of sub-categories by summing all entries according to six descriptive columns in the database: (1) **method reliability** – the perceived reliability of cost estimates, based on the type of publication and method of estimation (*low* or *high*); following Diagne et al. (2020b), 'high reliability' is accorded if either provided by pre-assessed materials (e.g. peer review, official reports) or using a documented, repeatable and/or traceable method when provided in other grey literature; (2) **region** – here, we split costs by major political unit in Australia (States and Territories), as well as costs not associated with any particular unit (i.e. national-scale or multiple states/not stated); (3) **implementation form** – this refers to whether the cost estimate was actually realised in the invaded habitat or merely predicted (*observed* or *potential*); (4) **type of environment**: *aquatic*, *terrestrial* or *mixed* habitats (species that spend part of their life cycle in water); (5) **type of cost** – (*i*) *damage/loss* (damage or losses incurred by invasion), (*ii*) *expenditure* (control-related expenditure, such as monitoring, prevention, management or eradication), (*iii*) *general* costs, including research and administrative costs and (*iv*) *mixed* types; and (6) **impacted sector** – the activity, societal or market sector that was affected by the cost – these were *agriculture*, *authorities-stakeholders*, *energy*, *environment*, *forestry*, *health*, *public and social welfare*, *protected areas* and *trade*. We modified individual cost entries not allocated to a single sector to *mixed* in the **impacted sector** column. We also provide several taxonomic summaries of the costs to provide the reader with a full appreciation of the relative scale of costs among different contributors. These include by taxonomic Kingdom and taxonomic Class.

Temporal development of costs

For the temporal estimation of the average annual costs, we used the custom `invacost` package in R (Leroy et al. 2020). This package provides functions for modelling the temporal trend of costs using a selection of both linear and non-linear models to provide a summary and comparison of their respective outputs. Given the evidence that numbers of invasive species show no sign of saturation (Seebens et al. 2017), we

expected their associated costs to be stable or increase. We accounted for the effects of time lags between the occurrence of the costs and their reporting by examining 'impact year' relative to 'publication year'. This is because there were often several years between the occurrence of costs and the time when they were reported in the literature (Diagne et al. 2021). Here, we determined from both the highly reliable, observed costs and all costs combined that the lag quantiles were: 25% = 0 year; 50% = 1 year and 75% = 3 years. We therefore estimated the 'final' costs for the year 2017 (i.e. three years prior to 2020) in the trend analysis described below – this ensures that we include only the most complete years in the trend analysis (i.e. years expected to have > 75% of cost data).

We applied five different models to quantify the temporal dynamics of reported $\log_{10}$ costs (*costTrendOverTime* function in the `invacost` package; now *modelCosts* in the latest version of R) because we had no *a priori* reason to assume that the trends were monotonic (linear or otherwise). The simplest approach is an ordinary least-squares regression (two variants: linear and quadratic to test for monotonic trends or non-linear behaviour, respectively). Additionally, we applied two variants of a robust regression (linear, quadratic – R package `robustbase`) (Maechler et al. 2020) because the cost data are heteroscedastic (unequal variances) and temporally autocorrelated. We therefore estimated the covariance matrix with heteroscedasticity and autocorrelation-consistent estimators (Andrews 1991) to derive 95% confidence intervals for our models. Robust (MM-type) regression (Yohai et al. 1991; Koller and Stahel 2011) applies iteratively reweighted least-squares to reduce the influence of outliers on parameters estimates. Finally, we applied a generalised additive model (GAM – R package `mgcv`) (Wood et al. 2016). Generalised additive models use smoothing functions to account for heteroscedasticity, based on a Gaussian location-scale model family. A more detailed description of the methods we applied is provided in Diagne et al. (2021).

We applied these five different models to both the entire cost dataset for Australia, as well as the highly reliable, observed costs only, to predict model-averaged 'final' (for 2017) (Diagne et al. 2021) estimated costs, based on the temporal trends of the full and subset data. This incorporates both parameter uncertainty estimated in individual models, as well as model uncertainty regarding the true underlying fit. We did this in two ways: (1) we first calculated Akaike's information criterion weights (Burnham and Anderson 2002) for the three likelihood-based models (ordinary least-squares regressions and generalised additive model) and (2) using the root mean-squared errors as weights to calculate a weighted-mean cost in 2017 (all five models). In addition to the `invacost` package, all R code and the Australia-specific dataset needed to reproduce the analyses can be accessed on Github via https://doi.org/10.5281/zenodo.4455979.

Results

Total cost

Since 1960, the total estimated cost of invasive species to Australia was US$298.58 billion (2017 value), based on 2078 unique entries (after removing 179 records pertain-

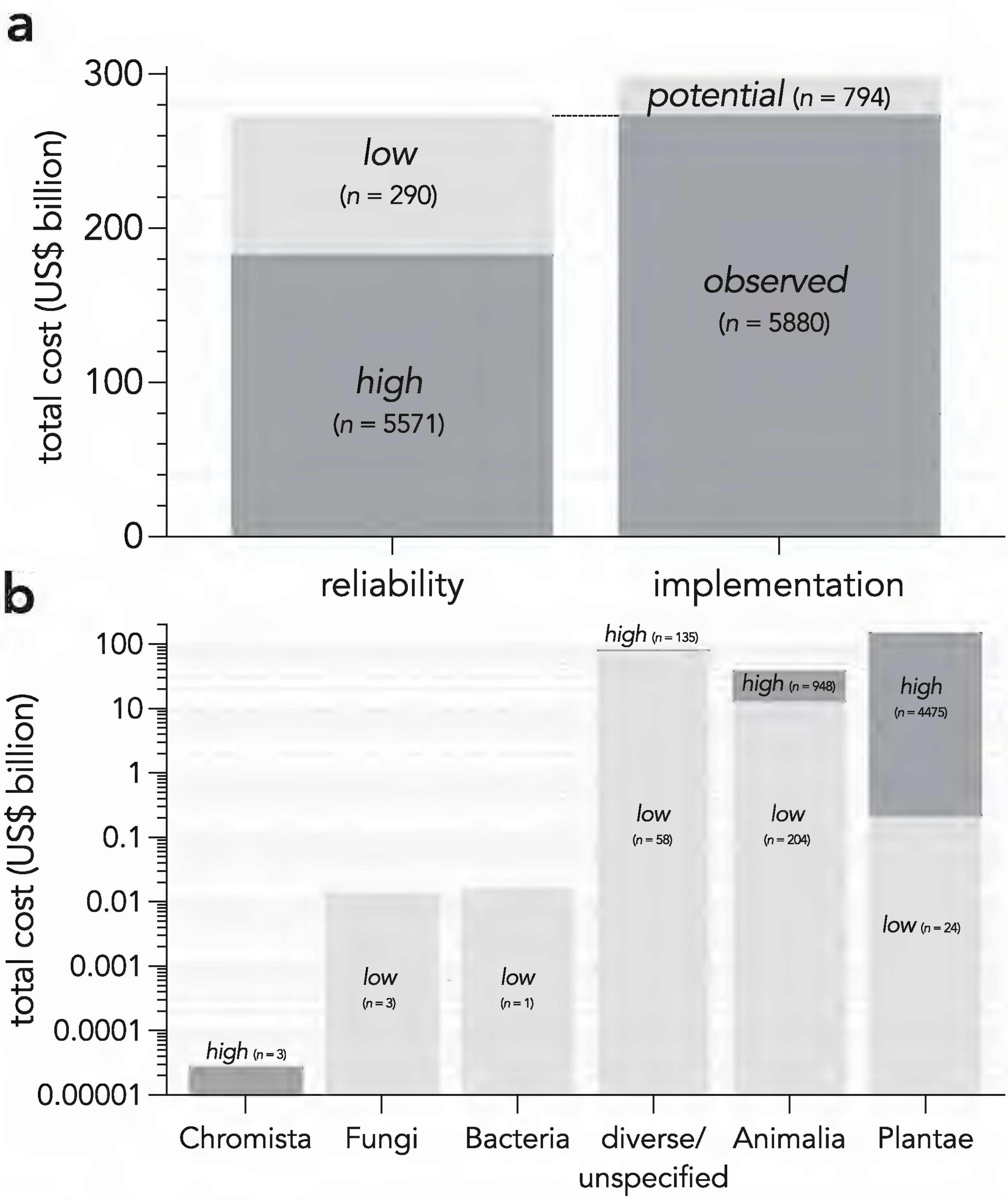

Figure 1. Division of total costs of invasive species in Australia relative to **a** reliability (*high*: dark grey or *low*: light grey) and the form of implementation (i.e. whether the cost estimate was realised [*observed*] or predicted [*potential*]) **b** costs according to major kingdoms. The number of unique database entries (*n*) in each category is indicated in brackets.

ing to avoided costs) in the combined database (6674 expanded yearly values), which is approximately equivalent to AU$389.59 billion (2017 average exchange rate). Of the total costs, the majority (91.6%) were observed (US$273.37 billion) rather than predicted or extrapolated ('potential'; US$25.21 billion) (Fig. 1a). Of the observed costs, most (61.3%) were considered highly reliable (US$183.04 billion).

Considering all costs regardless of reliability and implementation type, 27.6% of the total (US$82.29 billion) was not attributable to a single kingdom or was unspecified (Fig. 1b). This arises mainly from a multi-species assessment of costs of invasive species across all of Australia (Hoffmann and Broadhurst 2016). However, when considering only observed, highly reliable estimates, the costliest kingdom of invasive species was plants (US$151.68 billion), followed by animals (US$26.43 billion), with 'diverse/unspecified' making up only 2.7% of these (135 estimates amounting to US$4.93 billion) (Fig. 1b). There were few entries for Kingdoms Chromista (n = 3; US$27,970), Fungi ($n$ = 3; US$14.69 million; all low reliability; many of the fungal plant pathogens were not specified to Kingdom in the source data and so were designated 'diverse/unspecified') and Bacteria (n = 1; US$16.49 million; low reliability) (Fig. 1b).

There was a large disparity in the proportional attribution of costs by major political unit (States and Territories) whether estimating all costs or focussing on the highly reliable, observed costs only. Aside from the costs not clearly associated with a particular State or Territory (i.e. nation-wide or not specified), Western Australia had the highest total costs (52.7%) when considering all costs (US$17.88 billion) (Fig. 2a) – 69.3% of this value is attributed to rats *Rattus rattus* (US$12.39 billion), but > 99% of this estimate is considered to be of low reliability. When considering only the highly reliable, observed costs, New South Wales had the highest costs (US$5.25 billion), followed by Western Australia (US$4.58 billion) and Victoria (US$3.09 billion) (Fig. 2b).

There was an approximate power-law relationship between the number of unique database entries and the total costs per political unit for both all costs combined (Fig. 2c) or highly reliable, observed costs only (Fig. 2d). These relationships indicate that, with an increase of one order of magnitude in the number of estimates, the estimated costs increase on average by 2.0 (all costs) or 1.9 (highly reliable, observed costs) orders of magnitude. These power-law relationships were also evident for the cumulative data over time (Suppl. material 1: Fig. S1). The magnitude-order increase in costs with the number of database entries appears to be driven mainly by the variation in land surface area among political units (Suppl. material 1: Fig. S2); however, there is no relationship between costs and the number of database entries per unit area (Suppl. material 1: Fig. S2e, f), suggesting that the intensity of assessment of costs among political units is not systematically different. The Australia-wide or unspecified (to State/Territory) values probably represent some inevitable overlap with the cumulative estimates from the different regions; however, it is impossible to discern to what extent given unspecified attribution in many national-scale analyses (e.g., Hoffmann and Broadhurst 2016).

The costliest kingdom (plants) grouped most (96.5%) of its costs into the 'diverse/unspecified' category (Fig. 3b). Of the remaining highly reliable, observed costs identified to species, six species accounted for most (61%) of the remaining costs: annual ryegrass (*Lolium rigidum*), parthenium (*Parthenium hysterophorus*), ragwort (*Senecio jacobaea*), cucumis melons (*Cucumis* spp.), common heliotrope (*Heliotropium europaeum*) and wild radish (*Raphanus raphanistrum*) (Fig. 3b). Other invasive plants have

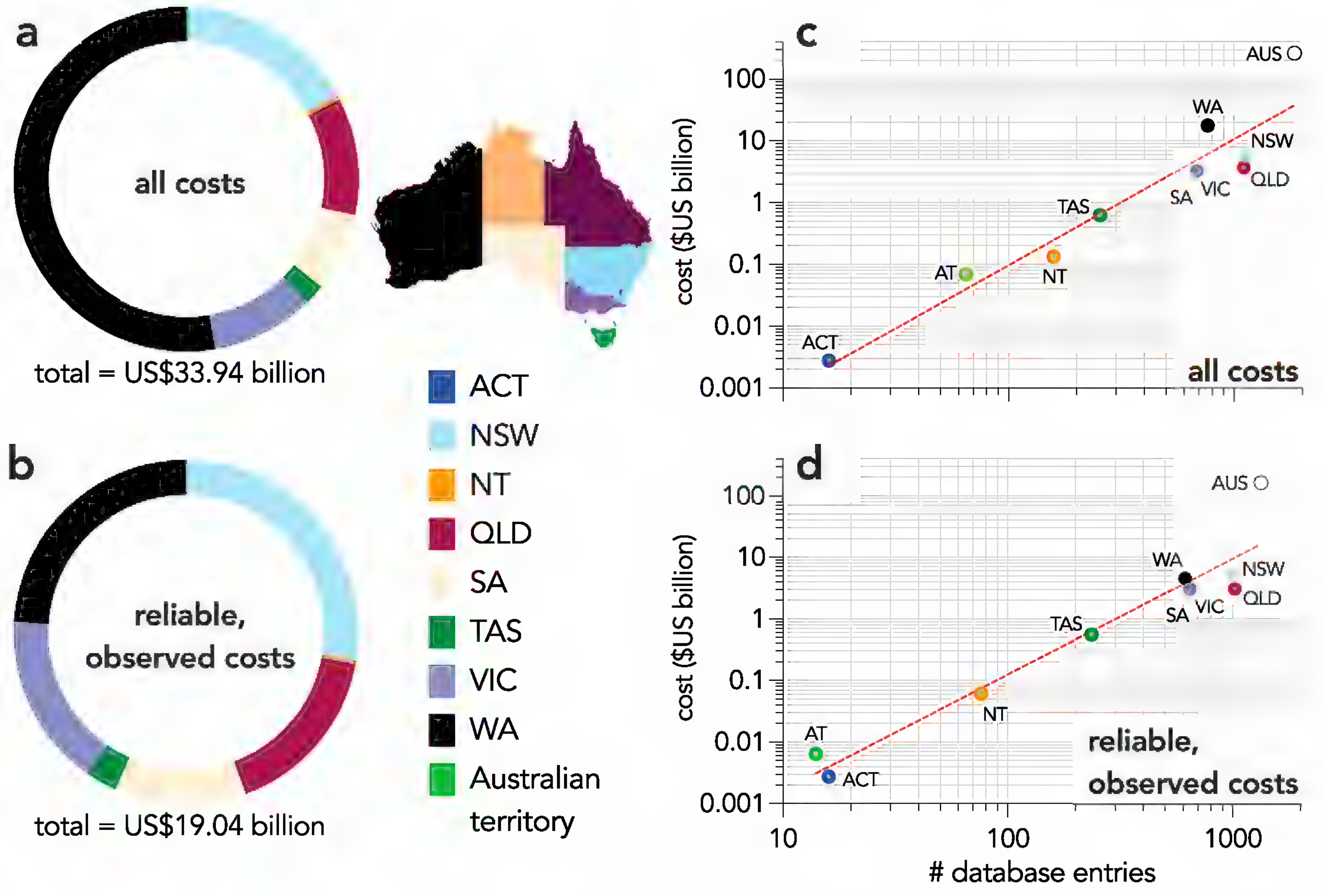

Figure 2. **a** sum of all costs according to attributable major political unit (States and Territories) **b** sum of highly reliable costs only by political unit **c** relationship between the number of database entries and all cost estimates by political unit – this also includes the estimate for 'Australia' ('AUS'; not directly attributable to a single State or Territory). The power-law relationship is also shown (evidence ratio = 18013, R^2 = 0.90) **d** relationship between number of database entries for highly reliable costs estimates by political unit (evidence ratio = 38550, R^2 = 0.91). Abbreviations: ACT = Australian Capital Territory; NSW = New South Wales; NT = Northern Territory; QLD = Queensland; SA = South Australia; TAS = Tasmania; VIC = Victoria; WA = Western Australia; AUS = nation-wide or not specified to which political unit the estimate belongs. 'Australian territory' refers to regions outside State/Territory jurisdiction (e.g. Christmas Island, Lord Howe Island).

historically had enormous negative impacts on Australian agriculture, but successful biological control programmes have largely eliminated these costs (e.g. prickly pear cactus and Paterson's curse *Echium plantagineum*) (Cullen et al. 2012). Some high-cost invasive grasses, such as gamba grass (*Andropogon gayanus*) (Northern Territory Government 2008), were invariably grouped within this 'diverse/unspecified' category and so species-specific cost estimates were not available. In Australia, exotic grasses have major environmental (e.g. gamba and buffel *Cenchrus ciliaris* grasses) and agricultural impacts (e.g. *Nassella* tussocks).

The costliest taxonomic classes of invasive species across all of Australia are mammals, insects and eudicots (respectively), although most estimates cannot be attributed to a single class (Fig. 3a). Among the mammals, cats, rodents (mice *Mus musculus* and rats *Rattus* spp.), pigs, rabbits and foxes had the highest costs, accounting for 95% of the total highly reliable, observed costs in this class (US$20.19 billion; Fig. 3c).

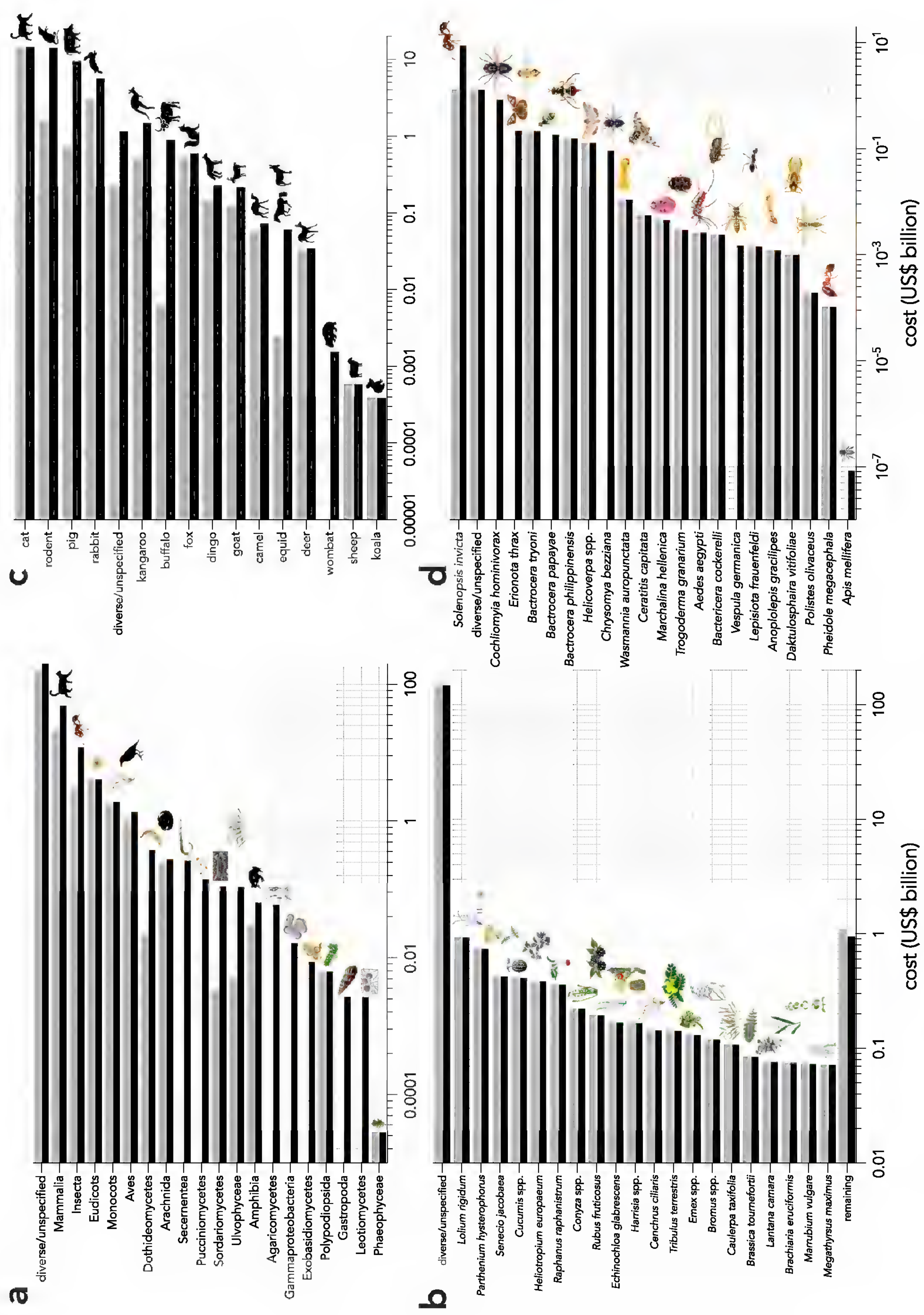

Figure 3. Sum of all (black) and highly reliable-only (grey) costs according to **a** taxonomic class **b** by plant species **c** by mammal species and **d** by insect species. We generally ordered these by the highly reliable costs, but, in some cases where there were no highly reliable costs for a particular category, we placed the category in the order suggested by total costs.

In fact, the category of 'diverse/unspecified' included these five taxa in many multi-species assessments; so, the costs attributed to these are actually higher. Including low-reliability costs would suggest that rodents – namely, house mice and rats *Rattus* spp. – were the second-costliest mammals, but most (89%) of this total was attributed to the low-reliability category. We also reported cost estimates for five native species groups, including various kangaroo species, koalas (*Phascolarctos cinereus*), common wombats (*Vombatus ursinus*), dingoes (*Canis dingo*) and Queensland fruit flies (*Bactrocera tryoni*) given that they are often considered 'overabundant' native 'pest' species because they compete for grazing resources (kangaroos), consume trees in *Eucalyptus* spp. plantations (koalas), burrow in paddocks (wombats), kill livestock (dingoes) or damage crops outside their native region (Queensland fruit fly). Kangaroos, koalas and wombats together account for only 3.1% of the total including all costs and 2.4% of the total highly reliable, observed costs (99.9% of which is attributed to kangaroos alone). Dingoes are native to Australia (Smith et al. 2019), but here we included all accounts of 'wild dogs', 'dogs' and 'dingoes' as dingoes – adding dingoes to the native-species groups increases the percentage represented to 3.5% (all) and 3.1% (highly reliable) (although this percentage is slightly higher in reality because dingo-related costs are sometimes combined with other species). Of course, many other native species cause extensive damage to the agricultural industry, such as birds and many insect species, but reliable estimates of the costs associated with most of these species have not been made for Australia.

Within the second-costliest class (insects), most (41.5%) of the highly reliable, observed total is within the 'diverse/unspecified' category (Fig. 3d). Of the highly reliable, observed cost estimates attributed to single species, 70.7% of the total is from the red imported fire ant *Solenopsis invicta* (US$1.29 billion), 11.8% from the (native to tropical Australia, but considered invasive elsewhere) Queensland fruit fly *Bactrocera tryoni* (US$215.45 million), 8.7% from the Pacific fruit fly *Bactrocera philippinensis* (US$158.91 million) and 7.1% from the bollworm *Helicovera* spp. (US$129.2 million) (Fig. 3d).

For the third-costliest class, based on all costs combined (Eudicots), five species account for most (56.7%) of all costs attributed to this class: parthenium (18.1%; US$740.66 million), ragwort (10.4%; US$425.37 million), cucumis melons (10.1%; US$412.12 million), common heliotrope (9.4%; US$384.25 million) and wild radish (8.8%; US$361.42 million) (Fig. 3b). Many of the other classes are dominated by one or a few species (Suppl. material 1: Table S1); for example, bird costs are either unspecified or from a single species: the common starling (*Sturnus vulgaris*); the Arachnids include only two mites: the red-legged earth mite *Halotydeus destructor* and varroa mite *Varroa destructor*; the Ulvophytes are represented solely by *Caulerpa taxifolia*; the Secernentids include only two nematode species (*Heterodera avenae* and *Pratylenchus* spp.); the Amphibia include only the cane toad *Rhinella marina*; the Polypodiopsids are represented only by *Salvinia molesta*; and the Phaeophyceae (brown algae) include only one species, wakame *Undaria pinnatifida* (see full species list in Suppl. material 1: Table S1).

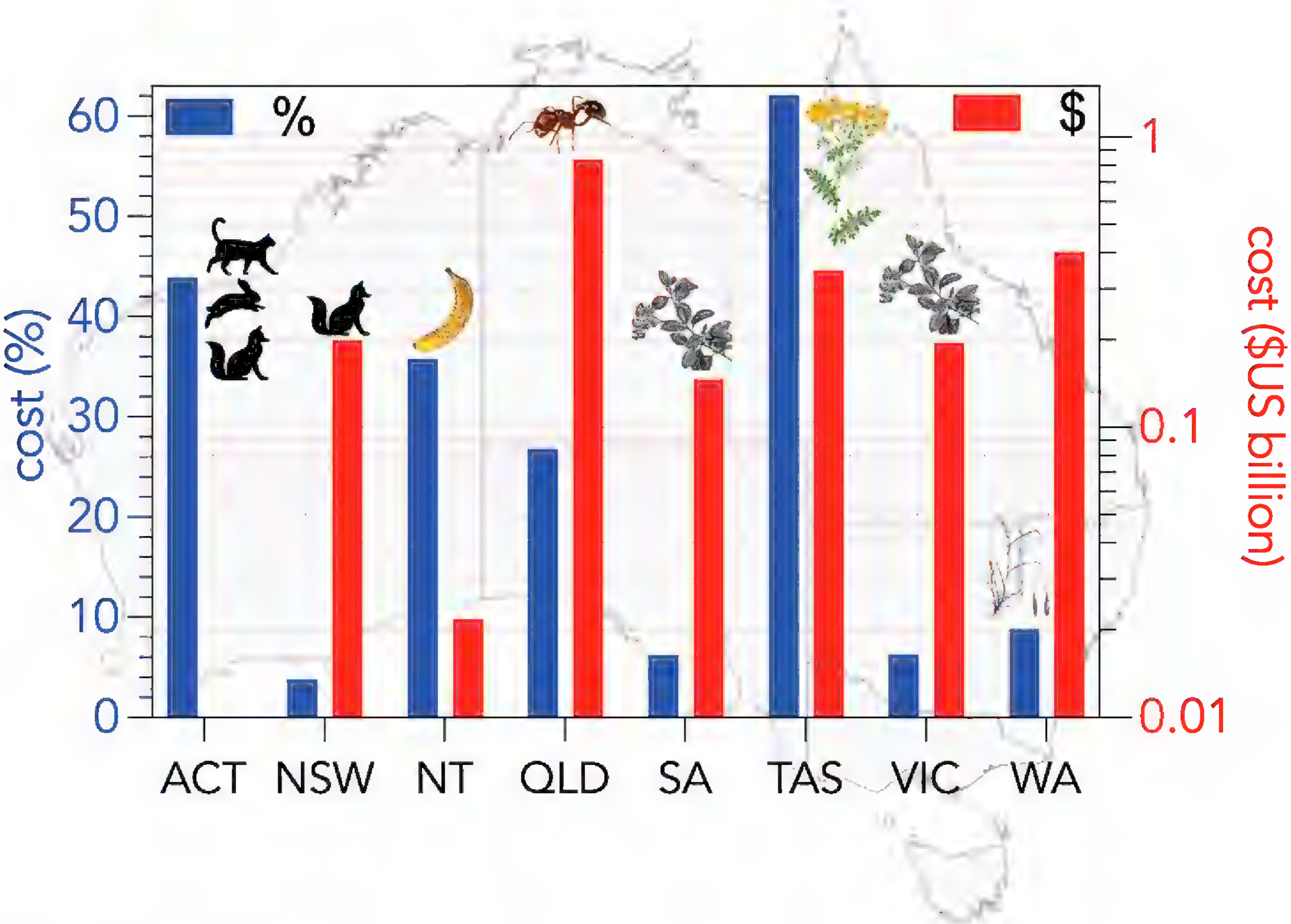

Figure 4. The costliest species (or group of species) per State/Territory. The left axis shows the percentage of the State's/Territory's total highly reliable, observed costs attributable to the species indicated and the right axis shows the value of these species in $US billion (2017 value). For all States/Territories, except Australian Capital Territory (ACT), Northern Territory (NT) and Tasmania, the costliest category is in fact diverse/unspecified. State/Territory abbreviations and species icons refer to: ACT = Australian Capital Territory (cats, foxes, rabbits); NSW = New South Wales (foxes); NT = Northern Territory (banana freckle disease *Phyllosticta cavendishii*), QLD = Queensland (red imported fire ants); SA = South Australia (common heliotrope *Heliotropium europaeum*); TAS = Tasmania (ragwort *Senecio jacobaea*); VIC = Victoria (common heliotrope); WA = Western Australia (annual ryegrass *Lolium rigidum*).

Various fungal rusts, smuts, rots, mildews and other plant pathogens were also featured in the database, accounting for > $697 million of the total reported costs (but only $25.1 million of the highly reliable, observed costs) (Fig. 3a). These included the Dothideomycetes (e.g. banana freckle disease *Phyllosticta cavendishii*), Sordariomycetes (e.g. wheat crown rot *Fusarium pseudograminearum*), Pucciniomycetes (e.g. wheat stripe rust *Puccinia striiformis*), Agaricomycetes (e.g. rhizoctonia disease *Rhizoctonia* spp.), Exobasidiomycetes (e.g. grass smut *Tilletia* spp.) and Leotiomycetes (powdery mildew *Blumeria graminis*).

The costliest species also vary among States/Territories (Fig. 4; also see Fig. 5). Mammals (cats *Felis catus*, red foxes, rabbits) are the costliest species only for Australian Capital Territory and New South Wales (Fig. 4). The Northern Territory's costliest species (36% of its costs) is the fungus *Phyllosticta cavendishii* that causes banana freckle disease. Queensland's costliest species is the red imported fire ant, representing 27% of the total

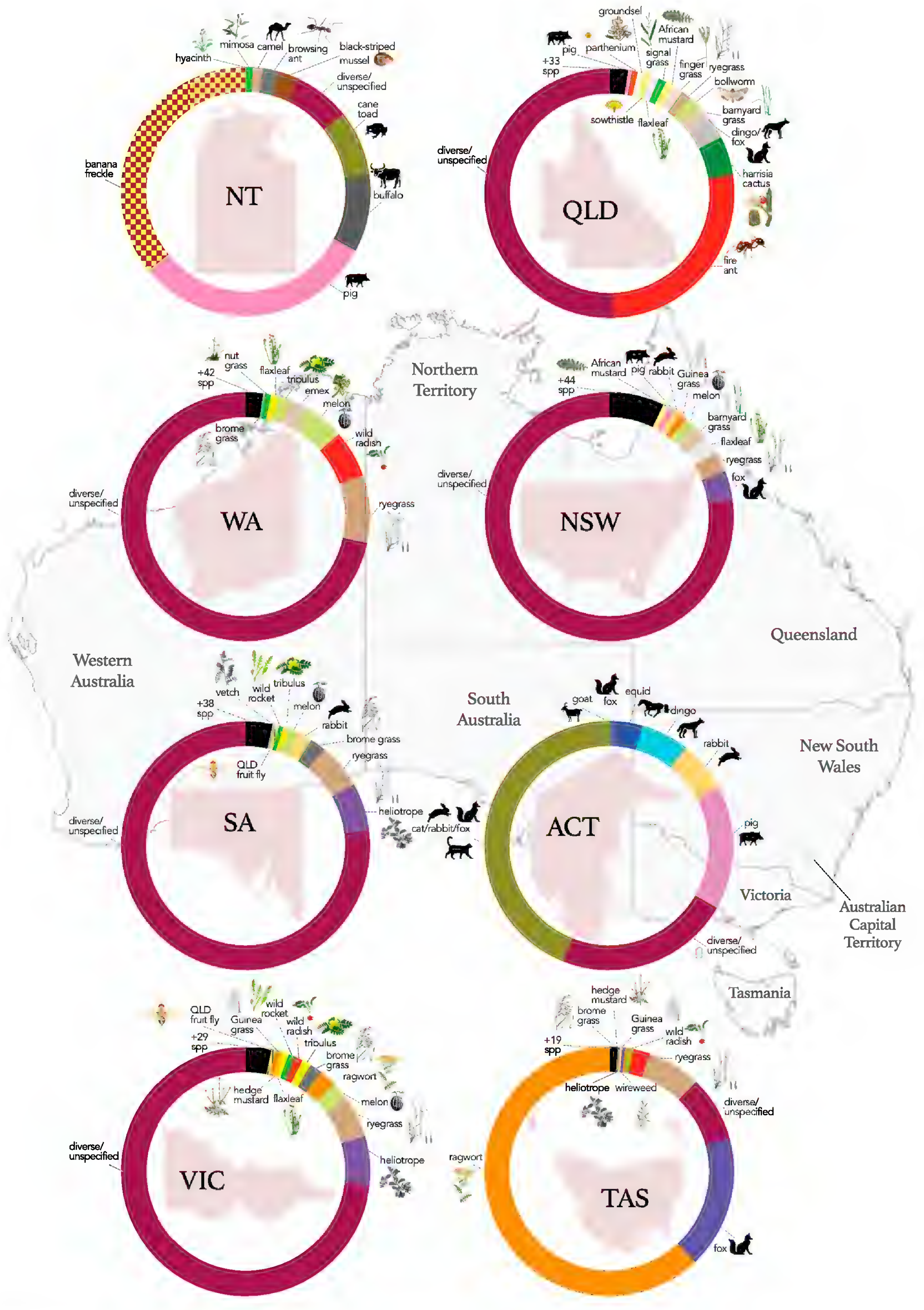

Figure 5. Proportional attribution of costs by species per State and Territory (highly reliable, observed costs only; refer also to Fig. 4). State/Territory abbreviations: ACT = Australian Capital Territory; NSW = New South Wales; NT = Northern Territory, QLD = Queensland; SA = South Australia; TAS = Tasmania; VIC = Victoria; WA = Western Australia. The full list of species (common and scientific names) is provided in Suppl. material 1: Table S1.

highly reliable, observed cost for that State (Fig. 4), whereas the common heliotrope is the costliest species for both South Australia and Victoria (6% of the total highly reliable, observed costs for those States). Tasmania's costliest species (62% of all costs) is the ragwort and Western Australia's is annual ryegrass (9% of total costs) (Fig. 4).

The proportional attribution of the highly reliable, observed costs by species per State/Territory is presented in Fig. 5.

The most impacted habitat is the terrestrial environment (39%), although most (60%) of the total highly reliable, observed costs could not be attributed to a single habitat type (Fig. 6a). Damage by or loss of economic opportunity (cf. management) from invasive species has the highest value (US$133.35 billion) among cost types (Fig. 6b), representing 72.9% of the total highly reliable, observed costs. The most-affected sectors are the agriculture (24.1%; US$44.03 billion), health (4.6%; US$8.37 billion) and environment (4.1%; US$7.58 billion) sectors, although most (65.8% of the total highly reliable, observed costs) affected multiple sectors (*mixed*; Fig. 6c).

Tracking temporal trends (Diagne et al. 2021), the costs attributed to invasive species in Australia increased from the 1970s to the present. Using all costs irrespective of reliability, the average annual cost increased from US$57.65 million in the 1970s to $20.19 billion during the last decade (Fig. 7a). Although highly variable from decade to decade, this equates to an average decadal increase of ~ 6.3-fold (or 3.2-fold, based on the slope coefficient for the linear robust regression only to compare directly to the 3-fold increase estimated from the global dataset) (Diagne et al. 2021). Taking only the reliable, observed costs, the average annual cost increased from over US$52.35 million in the 1970s to US$15.12 billion during the last decade (Fig. 7a) or an average 6.0-fold increase per decade (or 1.8-fold, based on the slope coefficient for the linear robust regression). This translates into a mean annual cost of US$5.85 billion (all costs) or US$3.58 billion (reliable, observed only) over the study interval (Fig. 7a). Examining the temporal trends in the observed, reliable costs only for three of the main taxonomic groups (plants, mammals, insects) shows the general increasing trend, although the most recent decade's increase is driven primarily by costs attributed to plants (Suppl. material 1: Fig. S3).

For both all-costs and observed, reliable datasets, the general additive model had the best fit assessed using the highest Akaike's information criterion weights (*w*AIC). However, the quadratic ordinary least-squares model had the best fit for the highly reliable, observed costs, based on the lowest root mean-squared error (RMSE; Table 1).

Using these weights to predict the annual costs in 2017 for both datasets, those based on *w*AIC are dominated by the GAM prediction, whereas those based on RMSE weights accord relatively more importance to the quadratic models (Fig. 7b, c).

For the all-costs dataset, the estimated annual costs in 2017 are US$18.77 billion (US$6.09 billion–US$57.91 billion) according to *w*AIC or US$17.88 billion (US$7.56 billion–US$45.44 billion) according to RMSE (Fig. 7b). For the highly reliable, observed data only, the predictions for 2017 are US$731.48 million (US$225.31 million–US$2.38 billion) according to *w*AIC or US$1.85 billion (US$484.85 million–US$6.84 billion) according to RMSE (Fig. 7c).

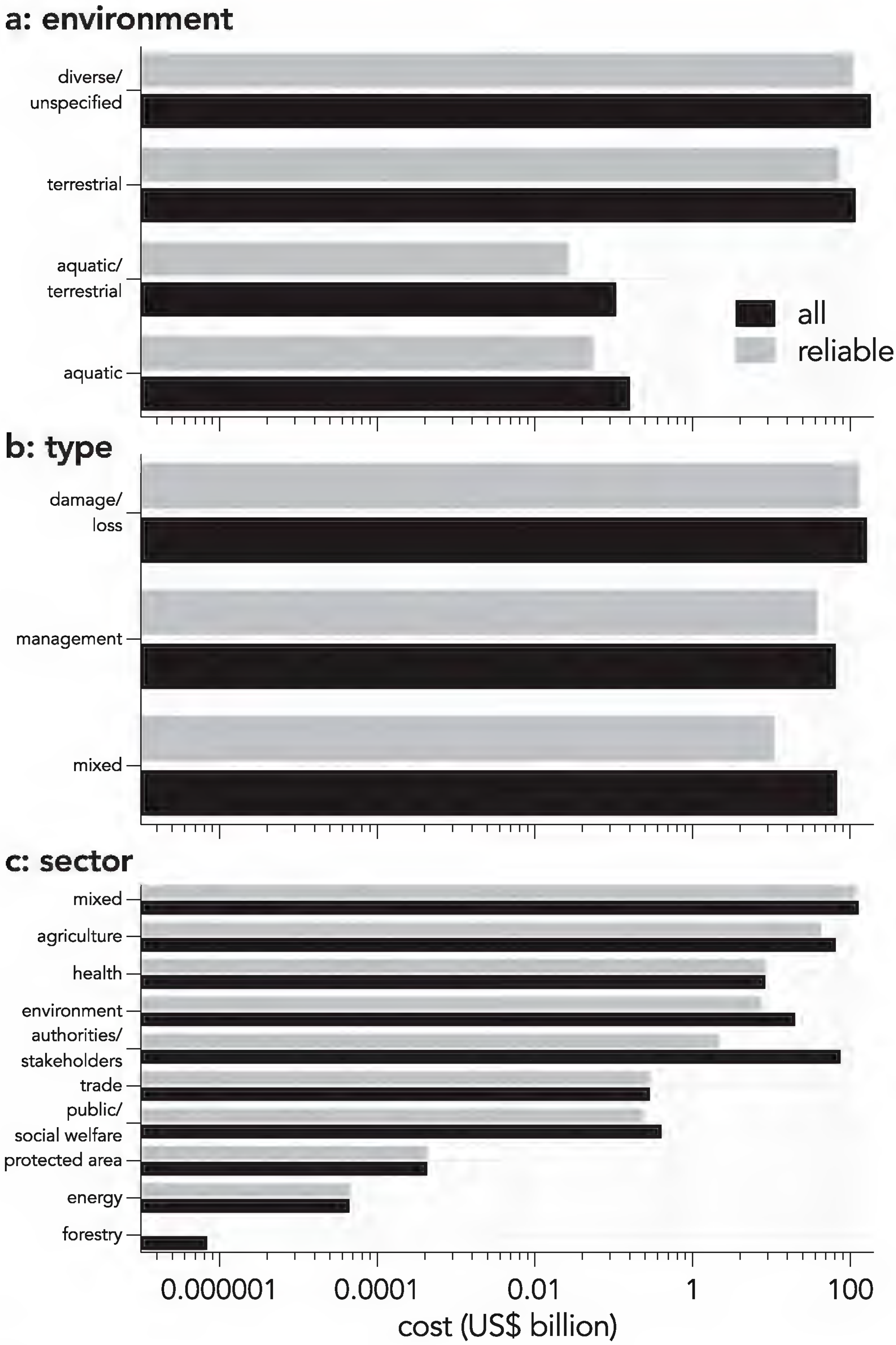

Figure 6. a sum of all (black) and reliable-only (grey) costs ($\log_{10}$ scale) according the impacted environment **b** cost type and (c) the major impacted sector.

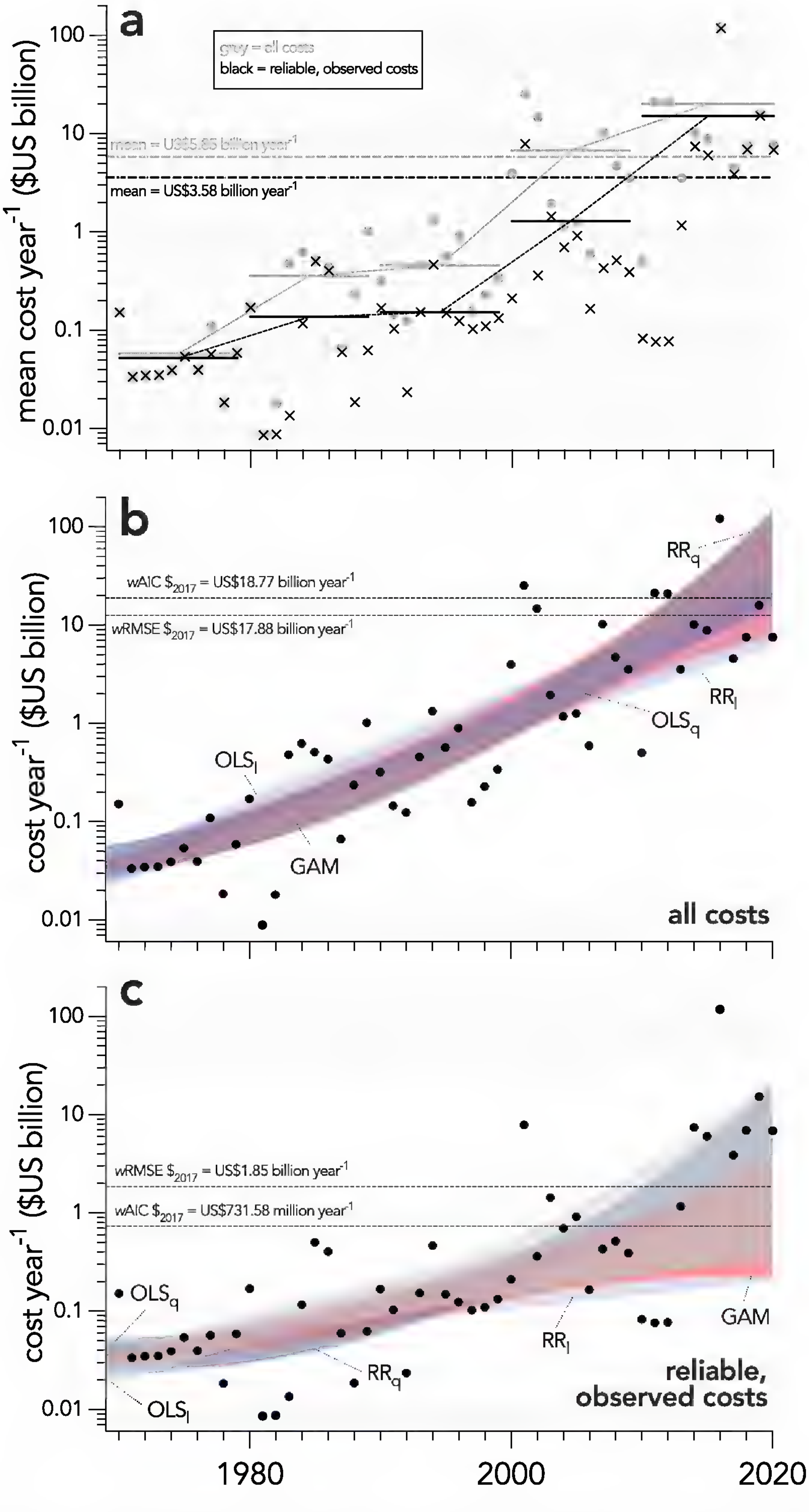

Figure 7. a raw annual costs for all costs (black) and reliable, observed costs (grey). Also shown are the decadal and overall means **b** predicted annual costs across Australia from 1970 to 2020 for all costs and **c** reliable, observed costs only. Fitted models include OLS_l = linear ordinary least-squares, OLS_q = quadratic ordinary least-squares, RR_l = linear robust regression, RR_q = quadratic robust regression, GAM = general additive model. Also shown in each panel are *w*AIC $\$_{2017}$ = Akaike's information criterion-weighted (*w*AIC)-average of the predicted annual cost in 2017 (all costs; OLS_l, OLS_q, GAM only), *w*RMSE $\$_{2017}$ = root mean-squared error-weighted average of the predicted annual cost in 2017 (all costs; all models), *w*AIC $\$_{2017}$, and *w*RMSE $\$_{2017}$ (reliable, observed costs only).

Table 1. Model fits to the temporal trend of annual costs from 1970 to 2020 for all data combined and for reliable, observed data only. Fitted models include OLS_l = linear ordinary least-squares, OLS_q = quadratic ordinary least-squares, RR_l = linear robust regression, RR_q = quadratic robust regression, GAM = general additive model. Also shown are Akaike's information criterion weights (*w*AIC) for the three likelihood-based models (OLS_l, OLS_q, GAM), the root mean-squared error (RMSE) for all models, the R^2 for each model (% deviance explained in the case of GAM) and the estimates of the relevant model coefficients (β_{year} and $\beta_{year}{}^2$) and their standard errors (± SE). See also Fig. 7.

model	*w*AIC	RMSE	R^2	$\beta_{year} \pm$ SE	$\beta_{year}{}^2 \pm$ SE
all data					
OLS_l	< 0.0001	0.4791	0.76	0.0528 ± 0.0041	–
OLS_q	< 0.0001	0.4798	0.78	-2.5449 ± 0.8721	0.0007 ± 0.0002
RR_l	–	0.4786	0.76	0.0509 ± 0.0041	–
RR_q	–	0.4779	0.79	-2.5807 ± 1.0377	0.0007 ± 0.0003
GAM	> 0.9999	0.4676	0.99	–	–
reliable, observed					
OLS_l	< 0.0001	0.5585	0.50	0.0337 ± 0.0074	–
OLS_q	< 0.0001	0.5271	0.55	-2.9986 ± 1.7180	0.0008 ± 0.0004
RR_l	–	0.5816	0.51	0.0251 ± 0.0055	–
RR_q	–	0.5277	0.71	-3.2653 ± 0.9690	0.0008 ± 0.0002
GAM	> 0.9999	0.5622	0.99	–	–

Discussion

Aggregated economic costs of the impacts and management of invasive species in Australia have amounted to at least US$298.58 billion (~ AU$389.59 billion) since the 1960s and US$183.04 billion (~ AU$238.83 billion) when conservatively considering highly reliable, observed costs only. Sampling biases notwithstanding (see below), the greatest economic burden to Australia imposed by invasive species originates from weedy plants, although most of these costs are shared across a wide range of species. This arises because of the 'top-down' approaches employed by others previously to estimate costs associated with losses and control specific to particular industries, rather than individual species (e.g., McLeod 2004; Sinden et al. 2004; Gong et al. 2009; Llewellyn et al. 2016). In many circumstances, this approach is more tractable and efficient for estimating total costs to particular sectors.

There are an estimated 2700 exotic plant species established in Australia, of which > 400 are declared weedy or noxious (Hoffmann and Broadhurst 2016). Our database contained highly reliable cost estimates for only ~ 100 species of declared weeds and many weeds did not have species-specific costs as described above. The cost of controlling and the damage done by weeds to the Australian agriculture sector alone are estimated at ~ AU$4 billion year^{-1} (Sinden et al. 2004; Hoffmann and Broadhurst 2016). However, from the perspective of single species, exotic mammals dominate the costs, with cats and rabbits, in particular, showing some of the highest estimates across the entire sample across Australia. For rabbits, it has been estimated that, without the highly successful biological control programme started in the 1950s, the impacts of rabbits in Australia would have been at least US$53.5 billion (~ AU$70 billion) higher over the last 50 years (Cooke

et al. 2013). However, the impacts of invasive mammals vary markedly by region, with the tropical regions suffering more from invasive fungi (i.e. banana freckle disease in the Northern Territory) and insects (i.e. red imported fire ant in Queensland) instead.

Hoffmann and Broadhurst (2016) estimated annual costs of invasive species in Australia (loss and management) in 2001–2002 at AU$12.9 billion and in 2011–2012 at AU$13.6 billion (2012 values), equivalent to approximately US$14.26 billion and US$15.03 billion (2017 value) for direct comparison to our estimates. The estimates of Hoffmann and Broadhurst (2016) hail from five different sources (Canyon et al. 2002; McLeod 2004; Sinden et al. 2004; Gong et al. 2009; de Hayr 2013) of unknown reliability and/or derived from stakeholder surveys. The management ('national') expenditure component of these were AU$3.0 billion and AU$3.8 billion for 2001–2002 and 2011–2012, respectively (or US$3.93 billion and US$4.20 billion, respectively; 2017 value). In contrast, our study incorporated appraisals of method reliability and implementation type when considering economic costs, presenting both 'total' and more conservative figures. Considering only those more conservative numbers, we found that damage and resource losses attributable to invasive species outweigh (73% of that total) management expenditure, but to a greater extent than indicated in those previous studies. This likely mirrors the relatively small investment of government funding for the management of most invasive species (Hoffmann and Broadhurst 2016) compared to the actual economic damages they incur. However, we acknowledge that our broad categorisations of cost type and implementation likely obscure subtleties associated with production losses, control costs and environmental impacts on a case-by-case basis. Reporting cost categories at finer resolution would likely invoke unacceptable subjectivity in reporting given the diversity of species, approaches, sectors, cost types, analyses and assumptions made in individual reports. We acknowledge, however, that the environmental and social costs recorded in InvaCost should be considered with some caution regarding their interpretation, because they are not strictly similar to market costs recorded in economic sectors (Diagne et al. 2020b). Further, cost categorisations for particular species likely shift in terms of emphasis during the course of invasions, meaning that management investment for many species begins with eradication costs and ultimately changes to suppression via control management as the species becomes established. Indeed, government investments typically target new incursions first, meaning that many of these are unlikely to be captured in the relevant literature.

As most cost estimates are damage arising from invasive plants (weeds), it is understandable why management-related costs represent such a small proportion of the total. However, one invasive mammal species is problematic in this regard – cats. According to the definition of 'reliable' provided for the overall InvaCost database – "Peer-reviewed articles and official documents (e.g. institutional or governmental reports) are likely validated by experts before publication. We assumed, therefore, that all cost estimates collected from these materials may likely be of high reliability" (Diagne et al. 2020b) – we were objectively obliged to include the damage estimate of US$5.95 billion for this species from Pimentel et al. (2001). However, that particular estimate was based on an unverified national population of 18 million feral cats and a subjective value of a bird

eaten of US$30 (amount to US$540 million year^{-1}) (Gregory et al. 2014). The subjective extrapolation of the costs of cats was also noted for the USA (Fantle-Lepczyk et al. 2021).

Compared to the global estimates (Diagne et al. 2021), the relatively well-sampled region of Oceania represents ~ 8% (range: 3–22%) of the total average annual costs globally in 2017 according to our database. Further, we found that Australia's rate of cost increase was up to ~ 2 times the rate of cost increase estimated from the global dataset (Diagne et al. 2021), although this observation might be explained in part by a lack of data in other regions compared to relatively well-studied Australia. However, Australia is still likely to be recording only a portion of the total costs of invasive species in the region. Although InvaCost, in general, as well as our enhanced sample from Australia more specifically, represent the most comprehensive and resolute assessments of the costs of invasive species yet available, there are several lines of evidence to suggest that the totals we report here still represent a vast underestimate of the real costs.

The first line of evidence is that the estimated total costs increased by approximately two orders of magnitude with every order-of-magnitude increase in the number of entries. This accords well with other assessments revealing that, as the number of estimates increases, so too do the total costs (Bradshaw et al. 2016; Cuthbert et al. 2021a; Diagne et al. 2021) – in other words, the more economic assessments are done, the more costs are discovered. While this could arise in part from the increasing rate of scientific and related publishing over the last 50 years (Richardson and Pyšek 2008), under-sampled or under-assessed species and regions will necessarily underestimate total costs. This particularly holds true to aquatic and semi-aquatic alien taxa in Australia, with the majority (99.9%) of costs attributed to a particular habitat (i.e. excluding mixed-habitat costs) being terrestrial (observed, highly reliable costs) and terrestrial taxa dominating in most regions. On the global scale, this aligns with the under-representation of aquatic invaders relative to terrestrial ones (Cuthbert et al. 2021b).

The second line of evidence is that many well-known invasive species established in Australia have no associated cost estimates in the database. For example, there was not a single estimate from the Reptilia in the database, yet species like red-eared sliders (*Trachemys scripta elegans*) and corn snakes (*Pantherophis guttatus*) are potentially costly species in some States of Australia (García-Díaz et al. 2017; Toomes et al. 2020). Neither were pet trade-sourced bird species like rose-ringed parakeets (*Psittacula krameri*) (Vall-llosera et al. 2017; Toomes et al. 2020) or fish pests, such as European carp (*Cyprinus carpio*) (Koehn 2004), identified in our cost database. Neither have native birds (Bomford and Sinclair 2002) or insects (Gu et al. 2007) that can heavily damage various crops been adequately assessed for costs (apart from the Queensland fruit fly). Indeed, Gong et al. (2009) reported that birds were the costliest vertebrate group to Australian agriculture. Despite reporting the costs for several fungal plant pathogens, there were notable absences; for example, we could not identify any reasonable costs estimates for *Phytophthora cinnamomi*, despite its being a major cause of crop losses and damage to biodiversity in Australia (Cahill et al. 2008; Hee et al. 2013).

The third line of evidence is that the InvaCost approach mandates avoiding the extrapolation of on-going costs beyond the time period specified by a particular source (Diagne et al. 2020b). We therefore included costs without a specified time window as

single-year costs, meaning that the resultant annualised costs represent a lower boundary of the true costs. While this avoids propagating positive errors through time, it downwardly biases the true mean costs. The fourth line of evidence is that the number of invasions in Australia has been increasing linearly for some time (CSIRO 2020), which is a notable improvement from the current exponential trend seen globally (Seebens et al. 2017); this accords well with our temporal analysis indicating an ongoing increase in recorded costs over last few decades (Fig. 7b, c). More broadly, lags in invader impacts considering their year of introduction (Rouget et al. 2016) could mean that it takes decades for economic costs to be realised and reported, just as it takes decades of introductions to become invasions (Essl et al. 2011). Accordingly, future economic impacts will likely result from a different suite of invasive species for which the effects have not yet been fully realised.

Conclusions

While the major costs of loss and damage arising from invasive species, where tangible, are probably captured reasonably well by our database (the under-sampling bias notwithstanding), management-expenditure estimates are perhaps less reliable. The component of the total costs of invasive species attributed to management expenditure is particularly problematic for several reasons. Indeed, there is no standard procedure for reporting expenditure or costs at any level of government or for private organisations, nor is there a national database of expenditure available (Hoffmann and Broadhurst 2016). A similar argument could also be mounted for damage and loss assessments regarding a lack of a standardised reporting protocol.

As our assessment highlights, the large and growing costs of invasive species to the Australian economy are substantial, but under-estimated because of insufficient coverage and a lack of standardised reporting by management authorities and other agencies. As invasive species continue to increase their ranges and associated impacts across the planet (Bellard et al. 2013, 2016; Seebens et al. 2017; Seebens et al. 2021), we can reasonably surmise that Australia will also suffer many additional, negative economic repercussions from invasive species over the coming decades. Developing better methods of estimating environmental impacts of invasive alien species will also contribute to this. We recognise that such types of economically intangible costs arising from invasive species (Bradshaw et al. 2016) are not captured by the database – for example, ecological damage, erosion of ecosystem services and loss of cultural values are inherently challenging to measure in this regard.

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References

Andrews DWK (1991) Heteroskedasticity and autocorrelation consistent covariance matrix estimation. Econometrica 59: 817–858. https://doi.org/10.2307/2938229

Bellard C, Leroy B, Thuiller W, Rysman J-F, Courchamp F (2016) Major drivers of invasion risks throughout the world. Ecosphere 7: e01241. https://doi.org/10.1002/ecs2.1241

Bellard C, Thuiller W, Leroy B, Genovesi P, Bakkenes M, Courchamp F (2013) Will climate change promote future invasions? Global Change Biology 19: 3740–3748. https://doi.org/10.1111/gcb.12344

Bomford M, Sinclair R (2002) Australian research on bird pests: impact, management and future directions. Emu 102: 29–45. https://doi.org/10.1071/MU01028

Bradshaw CJA, Leroy B, Bellard C, Roiz D, Albert C, Fournier A, Barbet-Massin M, Salles J-M, Simard F, Courchamp F (2016) Massive yet grossly underestimated global costs of invasive insects. Nature Communications 7: e12986. https://doi.org/10.1038/ncomms12986

Burnham KP, Anderson DR (2002) Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. Springer-Verlag, New York, 488 pp.

Cahill DM, Rookes JE, Wilson BA, Gibson L, McDougall KL (2008) *Phytophthora cinnamomi* and Australia's biodiversity: impacts, predictions and progress towards control. Australian Journal of Botany 56: 279–310. https://doi.org/10.1071/BT07159

Canyon D, Speare R, Naumann I, Winkel K (2002) Environmental and economic costs of invertebrate invasions in Australia. In: Pimental D (Ed.) Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species. CRC Press, Boca Raton, 45–66. https://doi.org/10.1201/9781420041668.ch4

Cooke B, Chudleigh P, Simpson S, Saunders G (2013) The economic benefits of the biological control of rabbits in Australia, 1950–2011. Australian Economic History Review 53: 91–107. https://doi.org/10.1111/aehr.12000

Crystal-Ornelas R, Lockwood JL (2020) The 'known unknowns' of invasive species impact measurement. Biological Invasions 22: 1513–1525. https://doi.org/10.1007/s10530-020-02200-0

CSIRO (2020) Australia's Biosecurity Future. Commonwealth Scientific and Industrial Research Organisation, Canberra, 37 pp.

Cullen J, Julien M, McFadyen R [Eds] (2012) Biological Control of Weeds in Australia. CSIRO Publishing, Melbourne, 641 pp. https://doi.org/10.1071/9780643104204

Cuthbert RN, Bartlett AC, Turbelin AJ, Haubrock PJ, Diagne C, Pattison Z, Courchamp F, Catford JA (2021) Economic costs of biological invasions in the United Kingdom. In: Zenni RD, McDermott S, García-Berthou E, Essl F (Eds) The economic costs of biological invasions around the world. NeoBiota 67: 299–328. https://doi.org/10.3897/neobiota.67.59743

Cuthbert RN, Pattison Z, Taylor NG, Verbrugge L, Diagne C, Ahmed DA, Leroy B, Angulo E, Briski E, Capinha C, Catford JA, Dalu T, Essl F, Gozlan RE, Haubrock PJ, Kourantidou M, Kramer AM, Renault D, Wasserman RJ, Courchamp F (2021b) Global economic costs of aquatic invasive alien species. Science of the Total Environment 775: e145238. https://doi.org/10.1016/j.scitotenv.2021.145238

de Hayr B (2013) National Landcare Survey Results. Landcare Australia, Canberra.

Diagne C, Catford JA, Essl F, Nuñez MA, Courchamp F (2020a) What are the economic costs of biological invasions? A complex topic requiring international and interdisciplinary expertise. NeoBiota 63: 25–37. https://doi.org/10.3897/neobiota.63.55260

Diagne C, Leroy B, Gozlan RE, Vaissière A-C, Assailly C, Nuninger L, Roiz D, Jourdain F, Jarić I, Courchamp F (2020b) *InvaCost*, a public database of the economic costs of biological invasions worldwide. Scientific Data 7: e277. https://doi.org/10.1038/s41597-020-00586-z

Diagne C, Leroy B, Vaissière A-C, Gozlan RE, Roiz D, Jarić I, Salles J-M, Bradshaw CJA, Courchamp F (2021) High and rising economic costs of biological invasions worldwide. Nature 592: 571–576. https://doi.org/10.1038/s41586-021-03405-6

Essl F, Dullinger S, Rabitsch W, Hulme PE, Hülber K, Jarošík V, Kleinbauer I, Krausmann F, Kühn I, Nentwig W, Vilà M, Genovesi P, Gherardi F, Desprez-Loustau M-L, Roques A, Pyšek P (2011) Socioeconomic legacy yields an invasion debt. Proceedings of the National Academy of Sciences of the USA 108: e203. https://doi.org/10.1073/pnas.1011728108

Fantle-Lepczyk JE, Haubrock PJ, Kramer AM, Cuthbert RN, Turbelin AJ, Crystal-Ornelas R, Diagne C, Courchamp F (2021) Economic costs of biological invasions in the United States. Proceedings of the National Academy of Sciences of the USA. [in press]

Freeman DB (1992) Prickly pear menace in eastern Australia 1880–1940. Geographical Review 82: 413–429. https://doi.org/10.2307/215199

García-Díaz P, Ramsey DSL, Woolnough AP, Franch M, Llorente GA, Montori A, Buenetxea X, Larrinaga AR, Lasceve M, Álvarez A, Traverso JM, Valdeón A, Crespo A, Rada V, Ayllón E, Sancho V, Lacomba JI, Bataller JV, Lizana M (2017) Challenges in confirming eradication success of invasive red-eared sliders. Biological Invasions 19: 2739–2750. https://doi.org/10.1007/s10530-017-1480-7

Gong W, Sinden J, Braysher M, Jones R (2009) The Economic Impacts of Vertebrate Pests in Australia. Invasive Animals Cooperative Research Centre, Canberra, 49 pp.

Gregory S, Henderson W, Smee E, Cassey P (2014) Eradications of Vertebrate Pests in Australia: A Review and Guidelines for Future Best Practice. PestSmart Toolkit publication. Invasive Animals Cooperative Research Centre, Canberra, 90 pp.

Gu H, Fitt GP, Baker GH (2007) Invertebrate pests of canola and their management in Australia: a review. Australian Journal of Entomology 46: 231–243. https://doi.org/10.1111/j.1440-6055.2007.00594.x

Hee WY, Torreña PS, Blackman LM, Hardham AR (2013) *Phytophthora cinnamomi* in Australia. In: Lamour K (Ed.) *Phytoophthora*: A Global Perspective. CABI, Wallingford, Oxfordshire, 124–134. https://doi.org/10.1079/9781780640938.0124

Hoffmann BD, Broadhurst LM (2016) The economic cost of managing invasive species in Australia. NeoBiota 31: 1–18. https://doi.org/10.3897/neobiota.31.6960

Holmes TP, Aukema JE, Von Holle B, Liebhold A, Sills E (2009) Economic impacts of invasive species in forests. Annals of the New York Academy of Sciences 1162: 18–38. https://doi.org/10.1111/j.1749-6632.2009.04446.x

Koehn JD (2004) Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways. Freshwater Biology 49: 882–894. https://doi.org/10.1111/j.1365-2427.2004.01232.x

Koller M, Stahel WA (2011) Sharpening Wald-type inference in robust regression for small samples. Computational Statistics and Data Analysis 55: 2504–2515. https://doi.org/10.1016/j.csda.2011.02.014

Leroy B, Kramer AM, Vaissière A-C, Courchamp F, Diagne C (2020) Analysing global economic costs of invasive alien species with the invacost R package. bioRxiv. https://doi.org/10.1101/2020.12.10.419432

Lever C (2001) The Cane Toad: The History and Ecology of a Successful Colonist. Westbury Academic and Scientific Publishing, West Yorkshire.

Llewellyn R, Ronning D, Ouzman J, Walker S, Mayfield A, Clarke M (2016) Impact of Weeds on Australian Grain Production: the Cost of Weeds to Australian Grain Growers and the Adoption of Weed Management and Tillage Practices. Grains Research & Development Corporation, Canberra.

Maechler M, Rousseeuw P, Croux C, Todorov V, Ruckstuhl A, Salibian-Barrera M, Verbeke T, Manuel Koller, Conceicao ELT, di Palma MA (2020) robustbase: basic robust statistics. R package version 093-6. cran.r-project.org/package=robustbase

McLeod R (2004) Counting the Cost: Impact of Invasive Animals in Australia 2004. Cooperative Research Centre for Pest Animal Control, Canberra, 82 pp.

McLeod R (2018) Annual Costs of Weeds in Australia. eSYS Development Pty Limited, Centre for Invasive Species Solutions, Canberra.

Northern Territory Government (2008) NT Weed Risk Assessment Report: *Andropogon gayanus* (Gamba Grass). Northern Territory Department of Natural Resources, Environment, The Arts and Sport, Palmerston, 28 pp.

Pimentel D, McNair S, Janecka J, Wightman J, Simmonds C, O'Connell C, Wong E, Russel L, Zern J, Aquino T, Tsomondo T (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. Agriculture, Ecosystems and Environment 84: 1–20. https://doi.org/10.1016/S0167-8809(00)00178-X

Pyšek P, Hulme PE, Simberloff D, Bacher S, Blackburn TM, Carlton JT, Dawson W, Essl F, Foxcroft LC, Genovesi P, Jeschke JM, Kühn I, Liebhold AM, Mandrak NE, Meyerson LA, Pauchard A, Pergl J, Roy HE, Seebens H, van Kleunen M, Vilà M, Wingfield MJ, Richardson DM (2020) Scientists' warning on invasive alien species. Biological Reviews 95(6): 1511–1534. https://doi.org/10.1111/brv.12627

Raghu S, Walton C (2007) Understanding the ghost of *Cactoblastis* past: historical clarifications on a poster child of classical biological control. BioScience 57: 699–705. https://doi.org/10.1641/B570810

Richardson DM, Pyšek P (2008) Fifty years of invasion ecology – the legacy of Charles Elton. Diversity and Distributions 14: 161–168. https://doi.org/10.1111/j.1472-4642.2007.00464.x

Ridpath MG, Waithman J (1988) Controlling feral Asian water buffalo in Australia. Wildlife Society Bulletin 16: 385–390.

Rouget M, Robertson MP, Wilson JRU, Hui C, Essl F, Renteria JL, Richardson DM (2016) Invasion debt – quantifying future biological invasions. Diversity and Distributions 22: 445–456. https://doi.org/10.1111/ddi.12408

Sagoff M (2008) Environmental harm: political not biological. Journal of Agricultural and Environmental Ethics 22: 81–88. https://doi.org/10.1007/s10806-008-9127-4

Saunders GR, Gentle MN, Dickman CR (2010) The impacts and management of foxes *Vulpes vulpes* in Australia. Mammal Review 40: 181–211.https://doi.org/10.1111/j.1365-2907.2010.00159.x

Seebens H, Bacher S, Blackburn TM, Capinha C, Dawson W, Dullinger S, Genovesi P, Hulme PE, van Kleunen M, Kühn I, Jeschke JM, Lenzner B, Liebhold AM, Pattison Z, Pergl J, Pyšek P, Winter M, Essl F (2021) Projecting the continental accumulation of alien species through to 2050. Global Change Biology 27: 970–982. https://doi.org/10.1111/gcb.15333

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jäger H, Kartesz J, Kenis M, Kreft H, Kühn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, van Kleunen M, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. Nature Communications 8: e14435. https://doi.org/10.1038/ncomms14435

Simberloff D, Martin J-L, Genovesi P, Maris V, Wardle Da, Aronson J, Courchamp F, Galil B, García-Berthou E, Pascal M, Pyšek P, Sousa R, Tabacchi E, Vilà M (2013) Impacts of biological invasions: what's what and the way forward. Trends in Ecology and Evolution 28: 58–66. https://doi.org/10.1016/j.tree.2012.07.013

Sinden J, Jones R, Hester S, Odom D, Kalisch C, James R, Cacho O (2004) The Economic Impact of Weeds in Australia. Technical Series No. 8. Cooperative Research Centre for Australian Weed Management, Adelaide, South Australia, 65 pp.

Smith BP, Cairns KM, Adams JW, Newsome TM, Fillios M, Déaux EC, Parr WCH, Letnic M, van Eeden LM, Appleby RG, Bradshaw CJA, Savolainen P, Ritchie EG, Nimmo DG, Archer-Lean C, Greenville AC, Dickman CR, Watson L, Moseby KE, Doherty TS, Wallach AD, Morrant DS, Crowther MS (2019) Taxonomic status of the Australian dingo: the case for *Canis dingo* Meyer, 1793. Zootaxa 4564: 173–197. https://doi.org/10.11646/zootaxa.4564.1.6

Toomes A, Stringham OC, Mitchell L, Ross JV, Cassey P (2020) Australia's wish list of exotic pets: biosecurity and conservation implications of desired alien and illegal pet species. NeoBiota 60: 43–59. https://doi.org/10.3897/neobiota.60.51431

Vall-llosera M, Woolnough AP, Anderson D, Cassey P (2017) Improved surveillance for early detection of a potential invasive species: the alien rose-ringed parakeet *Psittacula krameri* in Australia. Biological Invasions 19: 1273–1284. https://doi.org/10.1007/s10530-016-1332-x

Wood SN, Pya N, Säfken B (2016) Smoothing parameter and model selection for general smooth models. Journal of the American Statistical Association 111: 1548–1563. https://doi.org/10.1080/01621459.2016.1180986

Yohai VJ, Stahel WA, Zamar RH (1991) A procedure for robust estimation and inference in linear regression. In: Stahel W, Weisberg S (Eds) Directions in Robust Statistics and Diagnostics. Springer New York, New York, 365–374. https://doi.org/10.1007/978-1-4612-4444-8_20

Supplementary material 1

Figures S1–S3 and Table S1

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Data type: Additional data and analyses

Explanation note: **Figure S1.** Cumulative costs across Australia expressed relative to the cumulative number of estimates, with an approximate power-law model fit to (a) all costs and (b) highly reliable, observed costs only (also see Fig. 2). **Figure S2.** Power-law relationships between (a, b) total costs and land-surface area of different States/Territories, (c, d) database entries and total land-surface area and (e, f) total costs and database entries per unit area for all costs (top row) and highly reliable, observed costs only (bottom row). **Figure S3.** (a) Raw annual (observed, highly reliable) costs for plants, mammals and insects. Also shown are the overall annual means for each taxonomic group. **Table S1.** List of common and scientific names of species to which costs have been attributed in the Australian database.

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